UNIVERSITY COLLEGE CHICHESTER

An accredited college of the UNIVERSITY OF SOUTHAMPTON

School of Sport, Exercise and Health Science

Biomechanical Assessment of the Shoe-Surface Interface During the Golf Swing

by

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ABSTRACT

SCHOOL OF SPORT, EXERCISE AND HEALTH SCIENCE.

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A successful golf swing is dependent on the performance of a complex sequential action. This movement involves the feet, knees, rotation of the hips and trunk, which result in a transmission of forces and torques between the feet / shoes and the ground (Williams and Sih, 1998). The aim of this thesis was to investigate golf shoe interface aspects relevant to the golf swing process. One flat-soled, one traditional and three alternative spiked golf shoe sole interfaces were evaluated. Using a mechanical traction-testing device, specific linear forces and rotational torques were applied to the forefoot and whole-foot of the five different golf shoe sole interface designs on a grass covered force platform. Greater linear and rotational ground action forces were identified within the traditional sole (whole-foot limiting friction 1.01) and alternative sole conditions (whole-foot limiting friction Blue 1.00, Red 1.02, Yellow 1.01) when compared to a flat-soled shoe (whole-foot limiting friction 0.88). The traditional shoe was also identified to frequently produce greater friction (forefoot limiting friction 0.97) in comparison to the alternative shoe soles (forefoot limiting friction Blue 0.92, Red 0.91, Yellow 0.91). Due to the mechanical nature of the study it was important to gain an understanding of how the golf shoe sole interface interacted with the ground and if between-shoe differences were repeated when subjected to dynamic human movement during the golf swing. Dynamic analysis of the five soles identified two between shoe-sole differences ($P = <.05$); Driver back foot Tz range (BW.m) (Traditional shoe (15.98 ± 1.11) was significantly different to the Blue alternative ($12.77 \pm .83$) and flat-soled shoe ($12.73 \pm .85$)); and 7iron front foot, Mz maximum time (s) (Flat-soled shoe ($1.39 \pm .02$) was significantly different to Blue ($1.72 \pm .03$) Red ($1.71 \pm .03$) and Yellow ($1.72 \pm .04$) alternative spiked shoes). The low handicap group (0-7) produced significantly slower weight transfer times (s) when compared to the medium (8-14) and high (15+) groups within all club conditions (3iron Low $0.73 \pm .03$, Medium $0.43 \pm .02$ and High $0.41 \pm .02$; 7iron Low $0.76 \pm .01$ Medium $0.54 \pm .01$ and High $0.54 \pm .01$; Driver Low $0.70 \pm .01$, Medium $0.48 \pm .01$ and High $0.43 \pm .01$). However, no significant differences in forces or torques were identified between handicap groups. The findings contradict the previous mechanical testing results concluding mechanical traction tests are not an appropriate test of between shoe differences when relating the findings to the golf swing. The differences in forces created between the shoe and ground identified between the mechanical and dynamic studies was a result of the adaptation by the golfer to the footwear condition. Dynamic in-shoe pressure analysis identified regional pressures created between the golfer and shoe throughout the swing process. The highest peak pressures (N/cm^2) were associated with the lateral regions of the front-foot from the point of ball impact (Front foot Traditional (R5) 114.33 ± 6.29 N/cm^2; Back foot Traditional (R5) 7.18 ± 1.07 N/cm^2) supporting previous kinematic and ground action force findings. The traditional spiked shoe produced greater in-shoe pressures within the front foot lateral mid-foot region however all sole conditions provided significantly higher pressures within specific in-shoe regions at different stages of the swing process. The comparable between shoe findings support the previous dynamic findings.

The thesis enhanced current understanding of between shoe-ground and shoe-golfer interactions. Different demands were placed on the front and back shoes during the golf swing highlighting the need for asymmetrical shoe sole designs. Limited differences were identified between the different shoe sole interface designs, concluding that golf shoe interface designs are not effective for the demands of the golf swing, subsequently shoe outsole modifications were suggested.

CONTENTS

APPENDIX LIST

PUBLISHED WORK ARISING FROM THIS THESIS

LIST OF TABLES

CHAPTER 6
IN-SHOE PLANTAR PRESSURE MEASUREMENTS OF DIFFERENT GOLF SHOE SOLE DESIGNS

CHAPTER 7
DISCUSSION AND CONCLUSION

List of Figures

CHAPTER 3: GENERAL METHODOLOGY

CHAPTER 4: THE MEASUREMENT OF MODERN GOLF SHOE TRACTION PROPERTIES

CHAPTER 5:
PERFORMANCE CHARACTERISTICS OF MODERN GOLF SHOE SOLE AND SPIKE DESIGNS

CHAPTER 6:
IN-SHOE PLANTAR PRESSURE MEASUREMENTS OF DIFFERENT GOLF SHOE SOLE DESIGNS

CHAPTER 7:
DISCUSSION AND CONCLUSION

Declaration of Authorship

I Paul Worsfold declare that the thesis 'Biomechanical Assessment of the Golf Shoe Surface Interface During the Golf Swing' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this university;
- Where any part of this thesis has previously been submitted for degree or any other qualification at this university or any other institution, this has been clearly stated;
- Where I have consulted the published work of others, this is always clearly attributed;
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- Parts of this work have been published as a poster presentation, 'A Kinematic Analysis of Foot Movement Patterns During the Golf Swing'. Worsfold, P.R., Smith, N.A., and Dyson, R. (2002). World Scientific Congress of Golf IV. Royal and Ancient Golf Club, St Andrews, UK.

Signed: ....

Date: ....

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GLOSSARY OF TERMS

- **Couple** = An arrangement of two equal and opposite parallel forces that tend to cause rotation. When a couple is exerted on a body, it tends to produce angular acceleration. The magnitude of the turning moment is equal to the product of the size of the forces and the perpendicular distance between their lines of action. This distance between the lines of action of the two forces is called the moment arm.

- **Force** = A vector quantity, which means that is has both magnitude and direction. Force is measured in Newton's (N).

- **Force Platform** = An electromechanical device that gives electrical signals proportional to the components of force acting on it.
  - F_x Horizontally tending to push the foot laterally.
  - F_y Horizontally tending to push the foot backwards.
  - F_z Vertically upward.

- **Friction** = The tangential force acting between two bodies in contact that opposes motion or impending motion. If the two bodies are at rest, then the frictional forces are called static friction. If there is relative motion between the two bodies, then the forces acting between the surfaces are called kinetic friction. Friction can also be subdivided into **translational** and **rotational** friction components. Translational refers to a repositioning of the whole foot, as in sliding; and rotational, refers to a rotation of the foot around a point of contact on the shoe sole.

- **Ground Reaction Forces** = The forces that act on the body as a result of interaction with the ground. Newton's third law implies that ground reaction forces are equal and opposite to those that the body is applying to the ground.

- **Moment** = The turning effect produced by a force. Calculated as the product of the force and the perpendicular distance between the point of application of the force and the axis of rotation. $M = F X M.A.$ where M = the moment of the couple, F = the magnitude of one of the forces involved, and M.A. = the shortest, or perpendicular, distance between the lines of action of the two forces involved (moment arm).

- **Power** = The rate of doing work. Power is equal to the work done divided by the time during which the work is being done: $P = W/t$.

- **Pressure Insole** = A device that consists of small force transducers of known area. If this area is sufficiently small, the force on each element can be considered uniformly distributed and, thus, an estimate of pressure is available. This device gives more information concerning load distribution than a force platform because the pressures acting on various anatomical regions can be measured rather than just the resultant force acting on, for example, the whole foot.

- **Slipping** = The point at which applied force or torque exceeds the fricitonal component of the shoe sole interface with the ground.

- **Torque (Moment)**: A force that produces rotation; the rotational force about a point (e.g., torque is the force required to tighten a bolt).

Shoe Definitions:

- **Alternative Spike** = Polyurethane or kevlar spider or swirl shaped spike 1 - 3mm long fitted into the sole interface to penetrate into the turf.

- **In-shoe interaction** = The interaction between the golfers foot and shoe sole.

- **Shoe-ground interaction** = The interaction between the shoe sole and the ground.

- **Sole interface** = The outer shoe sole into which additional traction can be added.

- **Traditional Spike** = Metal 6 – 8mm long spike fitted into the sole interface to penetrate into the turf.

Swing / Golfer Definitions (described for a right-handed golfer):

- **Address / Stance** = Initial stationary golfing position prior to the backswing.

- **Backswing** = A clockwise rotation of the upper body and club away from the ball until the club reaches a horizontal position above the golfers head.

- **Back-foot** = Foot furthest away from the hole.

- **Buckling** = Hyper inversion of the foot causing it to move onto the lateral edge of the shoe sole.

- **Downswing** = An anticlockwise rotation of the upper body and club from the top of the backswing. The movement accelerates the club-head so it arrives at the point of ball contact moving at maximum speed.

- **Eversion** = Foot tilting onto the inner sole edge.

- **Follow-through** = A deceleration of the club-head following ball contact. The follow-through does not have a direct affect on shot outcome.

- **Front-foot** = Foot closest to the hole.

- **Inversion** = Foot tilting onto the outer sole edge.

- **Inwards rotation** (described for a left foot) = Heel rotating left.

- **Knee flexion** = Bending of the knee joint with an angle of greater than 15 degrees.

- **Outward rotation** (described for a left foot) = Heel rotating right.

- **Weight transfer** = Transfer of golfers body-weight between the back-foot during the backswing to the front-foot during the downswing and follow-through.

Shot Outcome Definitions:

- **Miss-hit (Hook, Slice, topped shots)** = hooked (hit left), sliced (hit right) and topped (hit too high up on the ball causing it to roll along the ground).

- **Straight shot** = A shot which stopped on the fairway in front of the hole.

CHAPTER 1: BIOMECHANICAL ASSESSMENT OF THE SHOE-SURFACE INTERFACE DURING THE GOLF SWING

1.1: THESIS INTRODUCTION

'The objective in golf is to displace the ball from one position to another in the least number of shots possible' (Richards *et al.*, 1985).

The golf swing may be regarded as the central element about which the whole game is built involving a complex sequence of body movements that culminates in the club-head striking the ball.

All actions of the golfer's body and the club, from the first movement following the address (the position adopted by the player before beginning the swing) must be co-ordinated into one smooth sequence (Pforringer and Rosemeyer, 1989). The swing requires a synchronized movement between the upper body (torso, arms, and shoulders) and the lower body (lumbar spine, legs and feet).

In both backswing and downswing the motion is essentially rotary. During the transition from the backswing to the downswing, the upper and lower halves of the body are moving in opposite directions. The swing is a lateral move in a frontal plane, involving a rotational motion that takes place along a longitudinal axis (Thomas and Pietrocarlo, 1996). These rotational movements cause the golfer's body weight transfer to the back-foot (foot furthest from the hole) during the backswing then transfer to the front-foot during the downswing and follow-through.

The difficulty in the golf swing is to produce the desired amount of force and apply it by means of the club-head through the centre of gravity of the ball in the direction of desired movement of the ball (Broer and Zenricke, 1986). Only by governing control and synchronisation of the body segments is it possible to determine the physical impact and the end trajectory of the ball. Within the succession of movements there is a need to adjust according to the demands of a given shot, forming a structured and calculated multiplicity of movements (Richards *et al.*, 1985).

The golfer must contend with a number of forces during the swing, such as centripetal force, with a tangential component. Cochran and Stobbs, (1968) also state the occurrence of centrifugal forces used to help generate rotational motion into the club-head, through the accumulated momentum of the golfer's body actions. The smaller object always swings wider and further (relative to their joint centre of gravity) (Cochran and Stobbs, 1968). The same principle occurs during the golf swing. Cochran and Stobbs, (1968) identified the golfer must act as a swinging counterbalance to resist such forces. According to Cochran and Stobbs, (1968) the counterbalancing effect upon the golfer's body, as a result of the swinging centrifugal force applied to them, enables a golfer to balance and stabilise the swinging action. This is likely to be a part of good co-ordination and firm base of rhythm and timing, suggesting that it is really what the word 'swing', in the golfing sense means, implying two masses pulling on each other. However during the swing the club is not swung around the golfer like a gate swings on its hinges, as the golfer is not a rigid and immovable object. The golfer must act as a balancing part of the general movement, a free-swinging entity, which is coupled at the ground surface by the golfer's shoes through shoe traction (spikes) offering resistance against the muscular force applied by the golfer's body to create the rotational forces.

Newton's Third Law of Motion states that for every action and reaction there are equal and opposite responses. This also applies to the golfer's body during the swing. "The golf swing must be executed from power originating from muscular-skeletal energy on the soles, which is utilised there as reactional forces back to the head speed of the club." (Kawashima *et al.*, 1998).

Where any transfer of energy or momentum takes place, by the interaction of forces between parts of the body, balancing forces and movements must also occur. The whole complex system of force and reaction, movement and counter-movement must finally be resisted at the golfer's feet (Cochran and Stobbs, 1968). The effectiveness with which the golfer co-ordinates these issues – greatest power generation on an effectively balanced, but far from rigid base will determine to some extent how well golf is played.

Motion of the various body parts triggers reactive forces from the shoe-ground interface yielding useful information of the foot biomechanics of the swing (Thomas and Pietrocarlo, 1996). The golf swing involves a build-up of torque; therefore the action of the golfer during the swing must start at the feet – the only fixed point. The whole momentum effect of the swing is thus applying itself via the feet against the ground. For a good swing it is important that a stable and firm base for both feet is established.

Initial thoughts that the movements and functions played by the feet were just a passive following of the lead given by the hips, and upper body have been dismissed through further kinematic and kinetic analysis (Irwin, 1982).

With the feet acting as a base to create force and torque it is fundamental that the feet are stable and supportive throughout the golf swing process. This support and traction has been gained through the incorporation of additional sole traction. Spikes have been inserted into the out-sole of the shoe with the purpose of penetrating or indenting the ground, to assist stability and allow the creation of greater friction at the shoe-ground interface (Broer and Zenricke, 1980).

The earliest evidence of golf shoes with additional sole traction was identified in a photograph of players in New Zealand dated 1893. Two of the golfers were shown wearing shoes with hobnails- short nails with large, rounded heads (Gibeault *et al.*, 1983). In the 1914 U.S. Open Walter Hagen was one of the first professional golfers to wear hobnail shoes in a professional tournament. By 1919 golf shoes with spikes were regarded as standard footwear (Hall *et al.*, 2000).

Any slipping of the feet means a loss of momentum transferred to the ball, since some of the force goes into moving the foot or feet. For this reason, spikes on golfer's shoes aid indirectly in imparting momentum to the ball. Since the spikes indent or actually pierce the ground, the penetration of the spikes provides resistance to movement between the shoe and surface that normal frictional forces might not provide (Williams and Sih, 1998). Spikes offer a surface, which can push directly against a vertical surface of the ground rather than an area (Figure 1.1), which pushes across a horizontal surface; in which case the reaction force has a greater dependence of friction and offers traction in accordance with Newton's Third Law of Motion.

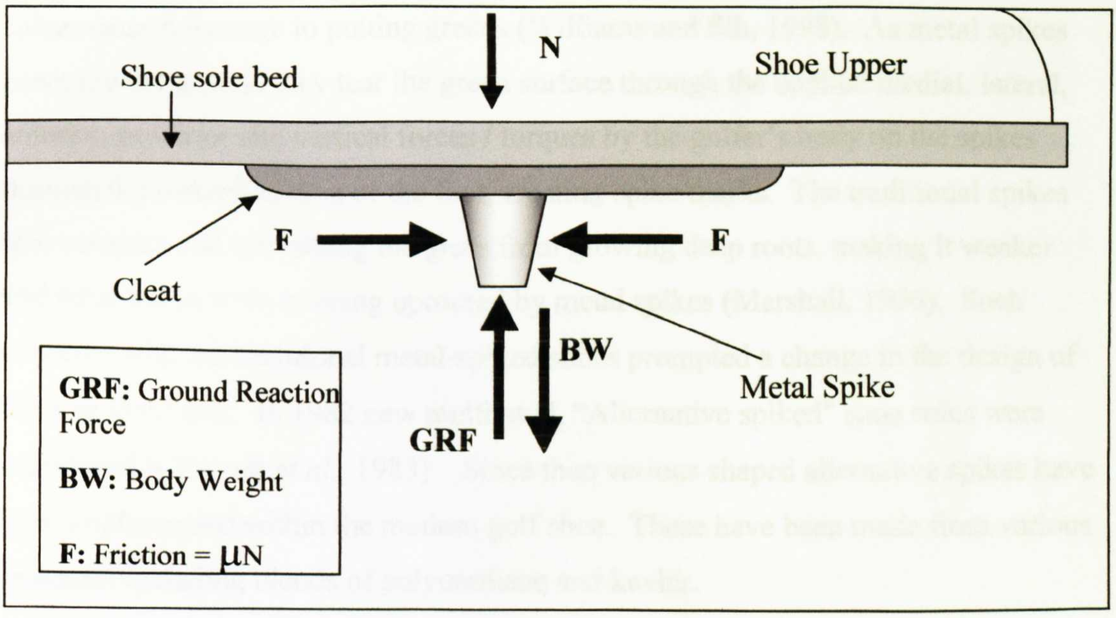


Figure 1.1. Forces Acting on the Metal Spike Whilst in the Shoe.

If the feet are directly under the hips, the pressure of the feet is more directly downward and slipping is less likely to occur. When the feet are placed apart further than the width of the hips more shear force is applied and the outward component of this force makes slipping more likely unless spikes are worn.

Since 1919, and until recently, metal spikes have been accepted as the standard traction devices for golf course footwear. These traditional metal spikes fit into the sole of shoes (either screw or quick lock), are 6 mm or 8 mm in length, and have a plastic base plate approximately 20 mm in diameter (Hall *et al.*, 2000) as shown in figure 1.2. The base plate of the spike was mounted close to the shoe sole with only the single metal spike protruding.

Figure 1.2. Examples of Traditional Metal Spikes.

Traction is achieved with these metal spikes due to their action of gripping roots, grass or soil (Marshall, 1996). There is, however, evidence that traditional metal spikes caused damage to putting greens (Williams and Sih, 1998). As metal spikes penetrate the ground they tear the green surface through the applied medial, lateral, anterior, posterior and vertical forces / torques by the golfer's body on the spikes through the natural motion of the foot, creating spike marks. The traditional spikes also compact soil preventing the grass from growing deep roots, making it weaker and more susceptible to being uprooted by metal spikes (Marshall, 1996). Such concerns with the traditional metal-spiked shoes prompted a change in the design of the sole interfaces. In 1982 new multi-stud, "Alternative spiked" shoe soles were introduced (Gibeault *et al.*, 1983). Since then various shaped alternative spikes have been implemented within the modern golf shoe. These have been made from various materials including blends of polyurethane and kevlar.

Alternative-spike systems' traction is provided by surface protrusions that penetrate only 1 - 3 millimeters into the turf, with some shoemakers fitting sole ripples in-between the spike origins to increase grip during the swing (Graham, 1993). Alternative spikes rely on contact surface area to grip the ground rather than the penetration enabled by the traditional single deep spike. Many designs incorporate swirl or spider effect protrusions to achieve this (see figure 1.3).

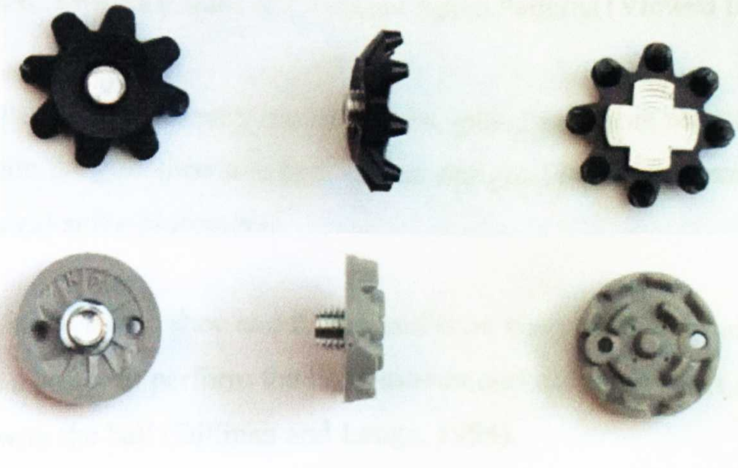


Figure 1.3: Examples of Alternative Spikes.

While various alternative spike designs have been introduced into the shoe soles the original shoe sole shape and spike locations have remained similar over the past fifty years (Horwitz, 1998). Only in the past fifteen years have manufacturers incorporated additional protrusions and grooves on the sole bed in addition to the spikes to gain extra traction. The two common patterns on the golf shoe incorporate six or seven spikes placed around the sole perimeter (Figure 1.4).

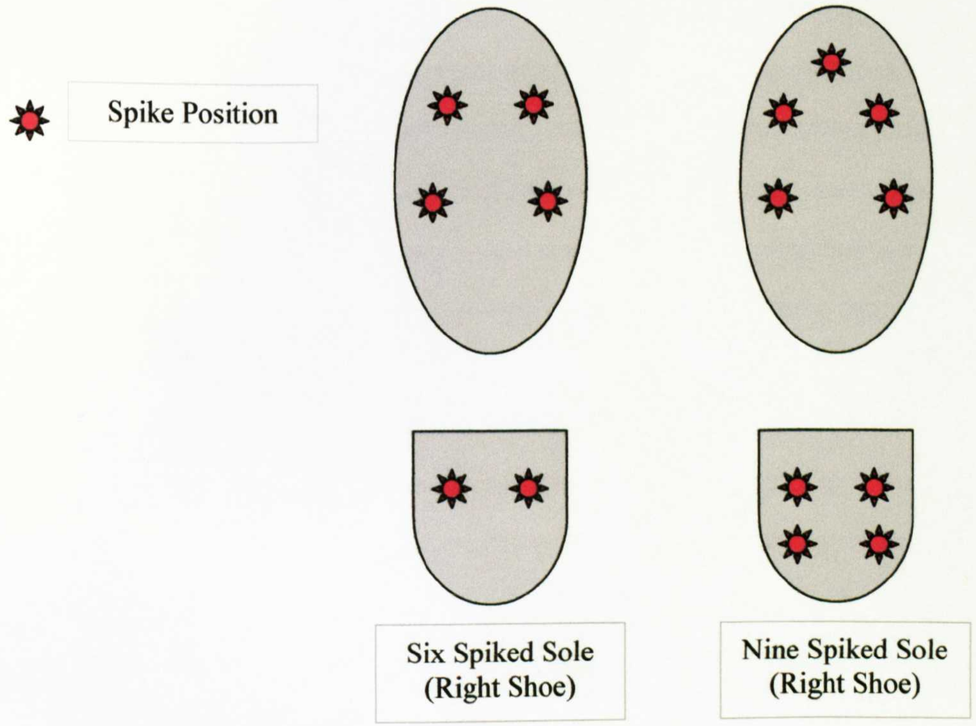


Figure 1.4. Two Examples of Common Spike Patterns (Viewed from Below).

Figure 1.4 identifies the customary traditional six spiked and more recent nine spiked positioning within the golf shoe sole bed. Shoes designed for the left and right feet have a symmetrical spike placement.

The interaction between the shoe and the ground have been recognised as the vital link that allows a golfer to perform the body movements during the golf swing that lead to impact with the ball (Dillman and Lange, 1994).

Thomas and Pietrocarlo (1996) highlighted that very little was known about the importance of the golf shoe and foot biomechanics until the pioneering study by Williams and Cavanagh (1983). Williams and Cavanagh's (1983) study of the mechanics of the foot action during the golf swing was one of the first to identify the movements and forces that occurred at the feet during the swing. They examined 10 golfers wearing one style of traditional metal spiked golf shoes, whilst playing shots in a laboratory based 'indoor golf station' which consisted of a single force platform. The platform was covered with 'Astroturf'. The golfers fell into three handicap groups low (0-7), medium (8-14) and high (15+) and used three different clubs; driver, 3iron and 7iron to hit a golf ball. The study identified the movements of each foot by alternately placing either the right or left foot on the platform during the performance of a golf swing with the different clubs. The research identified similar centre of pressure and force-time relationships between handicap groups. Williams and Cavanagh (1983) concluded that shear and vertical forces were important factors influencing stability, force production, and resistance to slipping during the swing. Modifications to the shoe sole configurations were recommended through altering the placement and inclination of spikes and using different designs for the right and left shoes, which were shown to have different functions.

Barrentine *et al.*, (1994) studied golfers in a similar indoor environment with two force platforms covered with artificial grass to measure ground reaction forces. Sixty golfers were divided into three groups, Professional Golfers Association (PGA) Tour professionals and coaching staff, low handicap (0-15) and high handicap (16+). Each subject performed a swing using a 5 iron and a driver whilst wearing 'flat-lasted' and 'Goodyear-welted' golf shoes though 'between shoe' result comparisons were not reported. Each subject performed 12 swings consisting of three trials for each shoe and club condition. However, even with such differences in testing modalities the findings of both these latter studies were similar.

The introduction of alternative spiked soles has caused fewer spike marks, and less soil compaction to golf courses, however their introduction has added another variable, which could influence foot movement and traction during the golf swing.

Many golfers have been reluctant to change to alternative spikes due to concerns about slipping during the swing despite the advantages to putting green maintenance. Slavin and Williams (1995) verbalised these concerns suggesting that it is likely that a shoe out-sole design with features that protrude less into the ground would be more susceptible to slip, and therefore cause adverse effects on the swing. Research into the functional performance of alternative spikes in comparison to traditional spikes was required. Slavin and Williams (1995) measured the static coefficients of friction (the ratio of shear force to vertical force when slip occurs) of 10 shoes differing in spike design (4 alternative, 5 traditional,1 flat-sole). The designs incorporated a flat-soled shoe, traditional metal 8 mm and alternative spiked designs. This was achieved by 'clamping' a sod of natural grass to a force plate and applying a vertical 35kg load to each of the shoes, utilising a wheeled cart system to initiate a constant force to the left shoe in a 'Forward direction in the horizontal plane along the axis of the shoe'. Each shoe was subjected to eight trials. Mean traction coefficient results ranged from 1.53 for the 8 mm traditional metal spiked shoe to 1.05-1.15 for the alternative shoes. The flat-soled shoe achieved a traction coefficient score of 0.73. They concluded that the flat-soled shoe without any spikes produced significantly less coefficients of friction when compared to all other shoe conditions while the traditional spiked shoe produced significantly greater coefficients of friction compared to all other shoe conditions, apart from one alternative spike design shoe. The results suggested that the modern alternative spikes did not offer the friction that the traditional metal spike offers suggesting "A higher probability of slip".

The study identified only static coefficients of friction for each shoe condition, as dynamic golfing actions (i.e. the golf swing) were not measured. Consequently it is unclear how the shoes / spikes would perform and compare if dynamic forces such as those created by the golfers feet and body during a golf swing were imposed. It is only these dynamic forces which truly enable the identification of the shoe / spike functional performance.

Williams and Sih, (1998) developed Slavin and Williams (1995) research by examining whether there were any changes in the force patterns exerted by the feet during actual golf shots, and if slipping was more likely to occur in alternative-spiked shoes. Within an indoor laboratory station Williams and Sih (1998) used two force platforms covered in "Artificial turf" to measure the ground reaction forces. Five subjects ranging in handicap (8-35) were asked to hit shots wearing a traditional 8 mm metal spiked shoe and an alternative spiked shoe. In addition one subject played shots with a flat-soled shoe. Maximum and minimum ground reaction force values were recorded during the time period before and after impact to identify differences in force magnitudes. A static coefficient / traction coefficient of friction (the ratio of shear to vertical force) was also determined for each shoe condition utilising a wheeled cart system to generate forces in a similar way to Slavin and Williams (1995). In Willams and Sih's (1998) study no significant differences were found in the maximum and minimum ground reaction force measures during the golf swing when the alternative spike design shoe was compared to a regular spike shoe during golf shots. No ground reaction force results were given for the flat-soled shoe. At present there are few studies identifying the traction of flat-soled shoes during the golf swing as it is generally assumed that the traction would be severely reduced. This has limited the general understanding of the shoe ground relationship and its influence on golf shoe traction, as such 'base line' measures is not known.

Williams and Sih (1998) did not identify any force or friction values for the flat-soled shoes and did not state if they were significantly different to the other shoe conditions while Slavin and Williams (1995) did identify a significant difference. Williams and Sih, (1998) research did not identify any significant differences in the static coefficient of friction results between the traditional and alternative shoe conditions further contradicting Slavin and Williams work, who identified significant differences between traditional 8 mm metal spike and alternative spiked shoes.

The golf swing is a complex movement, which, to a large extent, is influenced by the action of the feet (Barrentine *et al.*, 1994). With the feet being the only base of support during the swing, the interaction between the shoe and the ground provides the vital link that allows a golfer to perform the body movements of the swing (Dillman and Lange, 1994).

An understanding of forces and torques applied at the shoe to ground interface during the golf swing is essential for achieving proper mechanics and optimal performance (Barrentine *et al.*, 1994). The degree to which the force produced by the body is transferred to the ball depends upon the reaction force from the ground against the feet (Broer and Zenricke, 1980).

The frictional characteristics between sport shoes and surfaces have been measured for a variety of shoe and surface conditions, but the sport of golf has not been studied extensively (Valiant, 1993, and Williams and Sih, 1998). The shoe-surface friction permits golfers to use forces generated at the feet to create the swing motion required to impart force to the ball. Activation of the body's musculature enables a golfer to apply relatively large shear forces, which vary in direction and location on the feet according to the phase of the swing. The ground resists these forces by applying forces in the opposite direction via the spikes or frictional forces between the ground and out-sole (Slavin and Williams, 1995).

Recent technological advances have permitted more detailed biomechanical, kinematic and kinetic analyses of complex movements in golf, yet as Wallace *et al.*, (1990) pointed out, questions concerning body weight shift, foot movement patterns, as well as other kinematic aspects of the swing, have not been clearly answered. With little further significant research in the area since Wallace *et al.*, (1990) statement, there still is a lack of understanding of foot kinematics during golf swing performance.

In the last decade there has been growing realisation by the scientist, the customer, and the shoe manufacturer that the role of a sport shoe in sporting events can be quantified, and that the design and evaluation process can be aided by kinematics and biomechanical techniques. There have however been few scientific studies on the golf shoe ground relationship in comparison to those conducted into the design and development of golf balls and clubs (Barrentine *et al.*, 1994).

The aim of the research detailed within this thesis was to develop a greater understanding of the shoe / ground and shoe / golfer interaction. Through qualitative kinematic analysis of the lower limb movements, knowledge will be gained of the functions and requirements of the feet / shoes during the golf swing process. Through applying the previously identified golf swing specific movements to traditional metal spiked, alternative spiked and flat-soled sole interface designs using a mechanical traction testing device, individual tractional performance characteristics of each shoe sole interface will be gained within a controlled setting.

An investigation into the dynamic performance of the different shoe sole interface designs will give an understanding of their performance during the golf swing. The study will enhance knowledge of the shoe-ground interaction during the swing process. Between-shoe differences will be compared to the previous mechanical results. The study will enable analysis of handicap and club differences in relation to shot performance and shoe sole design.

An appreciation of the shoe / golfer interaction will also be gained through within shoe pressure measurements during the dynamic swing. The research will result in the generation of a more scientific understanding of the combination and functional necessities of the golf shoe / sole interface during the swing process based upon scientific measurement. The study will ascertain the key characteristics of each shoe sole interface through regional analysis and further identify optimal design features to facilitate and enhance the golf swing performance.

CHAPTER 2: FOOT MOVEMENT PATTERNS DURING THE GOLF SWING

2.1: INTRODUCTION

The golf swing involves complex synchronised movements of the upper and lower body, which develop fast and powerful rotary movement of the golf club. Throughout the rotational movement the golfer must apply and control resultant forces to strike the stationary golf ball in the desired direction. It is however not possible to describe an 'ideal' golf swing; as Jorgensen (1999) states, "The golf swing technique is determined by the laws of physics and the limitations of the human body which are different for everyone". The initial swing motion of the golfer must however start at the feet – the only fixed point. Slavin and Williams (1998) identified that correct biomechanical functioning of the foot plays a crucial, active and necessary role for the transference of weight and an effective swing.

Analysis of the movement of the lower limb and foot during the golf swing process would aid in the identification of the demands and requirements of a golf shoe and the moderations imposed by age and ability.

2.2: AIM

The purpose of the present study was to collect and analyse the movements of the lower extremities during effectively performed golf swings, which resulted in accurate ball strikes in the desired direction. Qualitative kinematic analysis of the lower body movements was performed to describe leg and foot movements during the golf swing process. The data were reviewed in relation to the type of golf shoe and sole design worn.

2.3: METHOD

Fifty-three right-handed male golfers volunteered for this study. Their mean and standard deviation characteristics were age: 28.7 ± 5.6 years, height: 175 ± 3.9 cm, mass: 75.84 ± 4.2kg. All subjects were members of Goodwood Golf Club (West Sussex) and played golf at least three times a month. The ground condition allowed the golf shoe spikes to penetrate (identified through visual identification of spike holes) the grass surface and the weather was dry and calm. Each subject provided informed consent before analysis began (see appendix a) and provided his or her golf handicap. Handicaps were classified as low (0-7), medium (8-14) and high handicap

(15+), as previous previously categorised by Williams and Cavanagh's (1983) research. Participants used their own golf clubs and shoes. Each subject performed one shot from the tee area, which was noted as either miss-hit or straight.

Procedure

Testing took place on the first tee (par five 510 yards / 466.34 meters). A note was taken of each golfer's shoe brand and the type of shoe traction used i.e. spiked or alternative spikes. The term "traditional spike" was used to classify traditional metal spikes with other forms of traction classified as "alternative spikes".
Each golfer was told to play their usual shot off the tee using their own club selection (driver, 3-wood, 3iron and 4iron).

Each participant was allowed as many practice swings as he wished before the actual swing was performed. Testing began when the player placed the ball on the tee and set-up into the address position. Throughout the whole golfing sequence two tripod mounted JVC GR-DVL 150 video camcorders set at a shutter speed of 1/250 per second recorded the frontal and saggital plane of the golfer's swing action. A diagram of the test environment can be seen in figure 2.1.

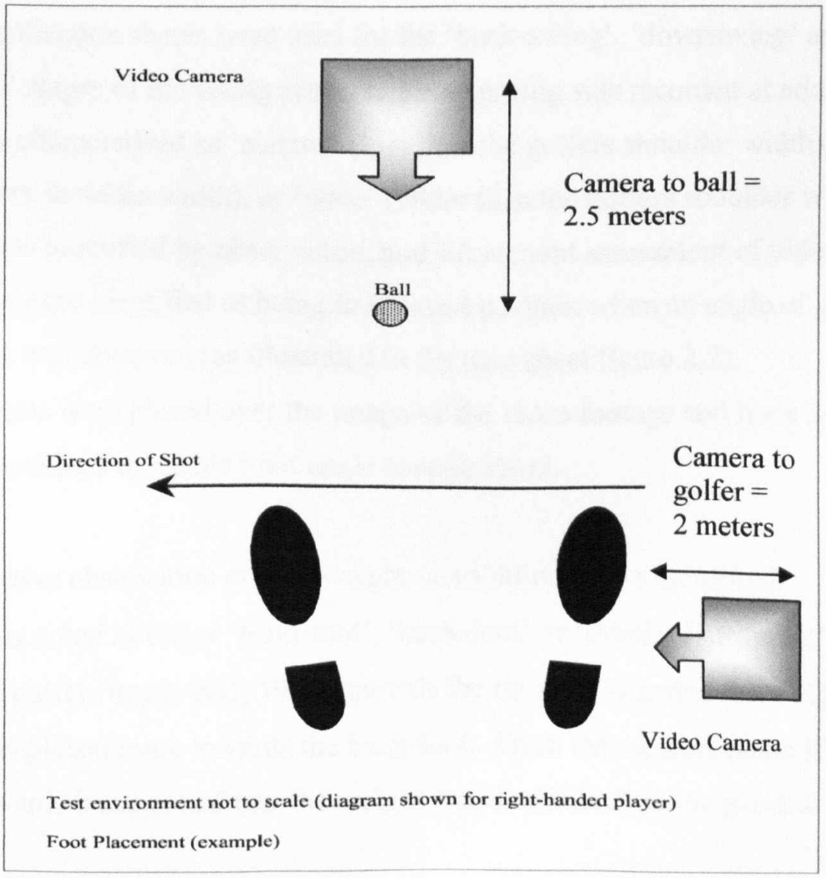


Figure 2.1. Test Environment.

Shot performance was visually observed and recorded as straight (stopped on the fairway in front of the hole) or miss-hit (miss-hit included hooked (hit left), sliced (hit right) and topped shots (hit too high up on the ball causing it to roll along the ground).

Data Analysis

Notational analysis of the movement patterns within each golf swing was conducted from the video footage viewed in slow motion. The swing was broken down into four parts, address (stance), backswing, downswing and follow-through. Hip, knee and foot movements were considered to identify individual body movements throughout the golfing performance. Information was recorded at the time of each swing and added to the data sheets during the actual swing process and subsequently when observing the video footage. The assessment sheets allowed golfer information, observed golfer body positions, and any further explanatory notes to be added.

Each lower body movement was recorded on assessment sheets for subsequent analysis. Figure 2.2 shows an example data sheet for the golfer at 'address'. Identical data collection sheets were used for the 'back-swing', 'downswing' and follow-through' stages of the swing process. Foot spacing was recorded at address and objectively characterised as 'narrow' (less than the golfers shoulder width), 'normal' (golfers shoulder width), or 'wide' (wider than the golfers shoulder width). Knee flexion was identified by observation, and subsequent assessment of video footage. Knees were identified as being in a flexed position when an angle of greater than 15 degrees was observed (as illustrated in the data sheet figure 2.2). Transparent sheets were placed over the image of the video footage and lines drawn over the knee positions to enable joint angle measurement.

Through subjective observation golfers weight distributions were identified. Distribution was noted as either 'front-foot', 'back-foot' or 'evenly distributed'. For example, if the golfers upper-body tilted towards the right it suggested the weight distribution was placed more towards the back-foot. From the saggital plane if the golfer lent forwards it suggested that the weight was distributed on the golfers forefoot.

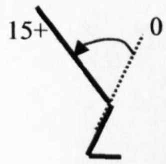
Club			
Handicap	Low (0-7)	Med (8-14)	High (15+)
Ball Position	Front-foot	Middle	Back-foot
Shoe Brand		Metal	Alternative
1) ADDRESS (SET-UP)	Left		Right
Knee Flexion 			
Body Weight Distribution			
		Forefoot	Posterior Foot
Left Foot Weight Distribution			
Right Foot Weight Distribution			
Distinctive Movement Characteristics			
Foot Placement at Address			

Figure 2.2. Data Collection and Analysis Sheet.

Any slipping or irregular foot movements during the swing were recorded after confirmation from the subject that the irregular movement was not their normal swing movement.

The qualitative data collected during the shot performed and video analysis was collated on tally and frequency charts. This information was transferred into Excel spreadsheets to allow calculation of descriptive statistics and percentages.

2.4: RESULTS

Golfers wore golf shoes fitted with either traditional metal or alternative spikes as shown in figure 2.3.

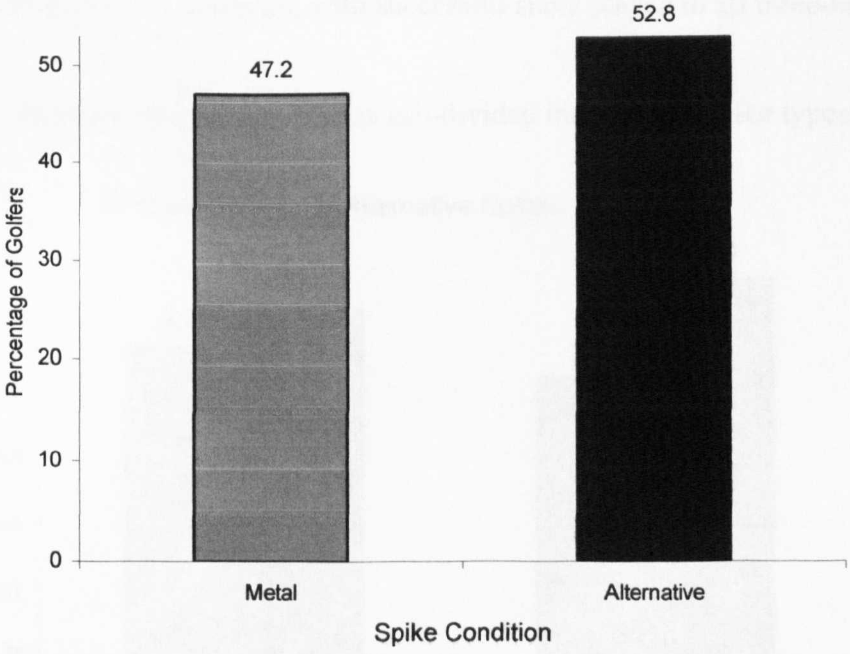


Figure 2.3. Spike Conditions Used by Golfers.

The fifty-three players were divided into three handicap groups, 20.8% had low (0-7), 41.5% had medium (8-14) and 37.7% had high (15+) handicaps. Figure 2.4 illustrates the use of traditional metal spikes and alternative spikes within the handicap groups. Notably the use of shoes with alternative spikes was more prevalent within the medium handicap group.

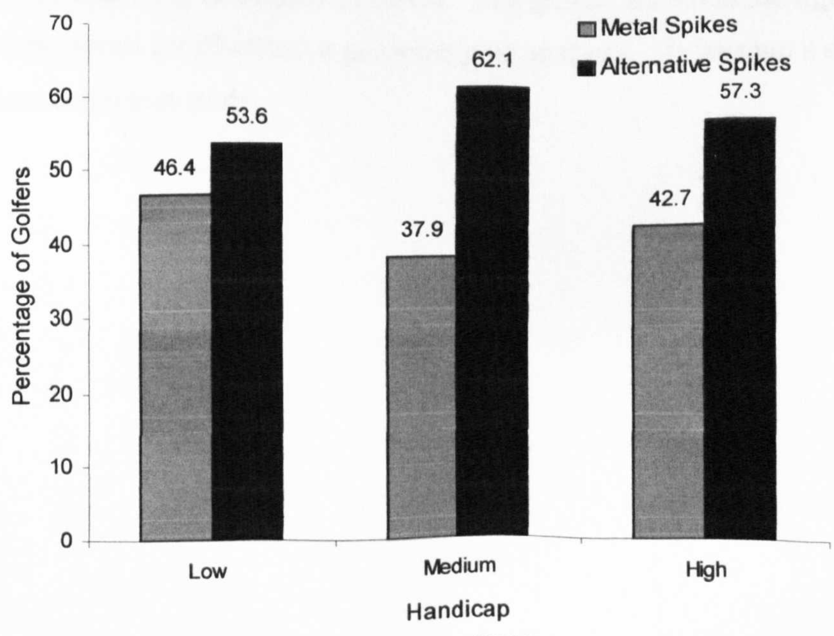


Figure 2.4. Spikes Used by Golfers of Different Handicap Groups.

Within the study the shot outcome count overall identified 60.4% were straight shots, 39.6% were miss-hits. The straight shot outcome did not always come from those players with the lowest handicap, with successful shots played in all three-handicap groups.

Figure 2.5 illustrates the shot outcomes sub-divided into the two spike types.

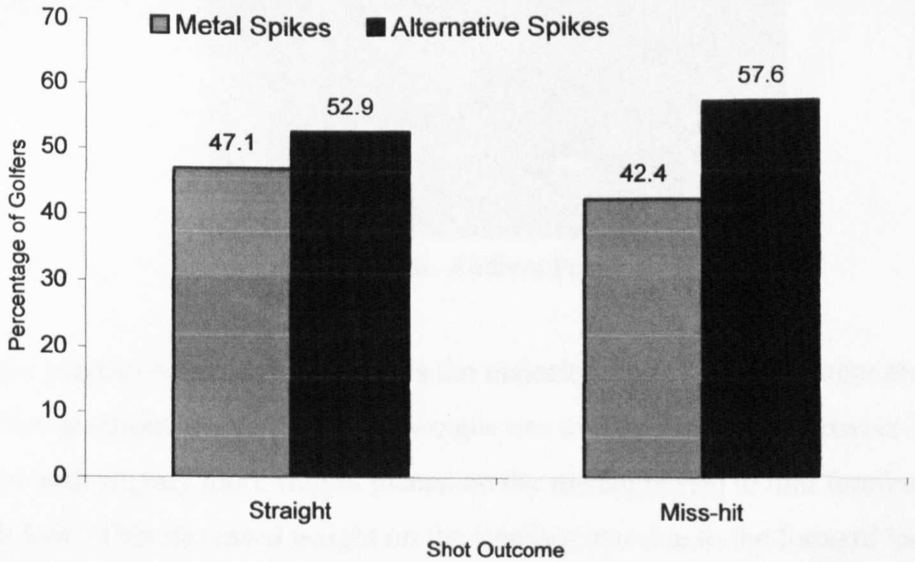


Figure 2.5. Shot Outcomes in Relation to Spike Type for all Golfers.

For the purposes of kinematic analysis the golf swing was divided into four major parts, the address (set-up), backswing, downswing / impact, and follow-through. The results are described for a right-handed player with the findings being the same but in the opposite direction for left-handed players. The golfer, shown in the figures, adopted the positions for illustrative purposes post analysis. He was not a subject in the main data collection study.

Address

The typical initial set-up position situated the club and body over the ball with the left shoulder toward the target (Figure 2.6).

Figure 2.6. Address Position.

From the subjective qualitative analysis the majority of golfers (87%) appeared to adopt foot positions where their body weight was evenly distributed between both feet, but with slightly more weight placed on the medial (43%) to mid forefoot (36%) of each foot. This increased weight on the forefoot was due to the forward lean of the upper body over the ball. Both knees were flexed to maintain stability and help induce the slight forward lean.

Backswing

The first major movement of the swing is the backswing. The aim of the backswing is to put the golfer and the club into a position from which to start the acceleration of the club into the downswing.

The first initial action occasionally identified a 'pressing' or 'cocking' motion in which the golfer slowly adducted the right knee in towards the left one and then (see figure 2.7), as the knee returns to its original position, the withdrawal of the hands and club then followed. This movement was evident in 47% of the golfers.

Figure 2.7. Example of 'Knee Press' at Address.

A simultaneous backward movement of the club-head and a rotation of the trunk to the right then occurred, causing a weight shift, moving onto the right foot with the left foot carrying less weight.

From the subjective analysis the golfers' weight was viewed to be either evenly distributed on the back-foot (34%), on the lateral side (30%) or maintained a slight medial position recognised by the rear foot position (36%). It was evident that this weight shift must occur in a controlled manner to maintain a stable platform. Analysis of the unsuccessful shots indicated 25% were derived from a large 'swaying' movement caused by a shifting of body weight to the lateral edge of the right foot. Without an exact reversal of the exaggerated sway in the downswing, the swaying resulted in less than optimal contact with the ball causing many to hit shots to the right (sliced) with no power. In contrast a more controlled transfer of weight to the right foot during the backswing was observed more often during successful shots. One of the critical elements during the swing was the constraint of the right knee during the backswing (Figure 2.8). This was identified within the low handicap players who kept their right knee braced close to its address location during the backswing, putting the knees in position to lead the downswing.

Figure 2.8. Right Leg Maintains Stable Braced Position.

As the right-foot remained in a solid position on the backswing without excess rolling to the lateral edge as figure 2.9 shows, the left foot was in turn rolling to the inside into an everted position (85%).

Figure 2.9. Left Foot Rolling to the Medial Edge.

A left heel raise occurred in 26% of the golfers as a result of foot plantar flexion helping promote a full shoulder turn, until the golf club was situated over the right shoulder. The heel raise was an individual trait that participants had adopted but had no positive or negative performance related outcomes. Completion of the backswing appeared to placed the weight on the right foot, evenly distributing the majority of the body weight between forefoot and rear foot and the mid to lateral border, with the weight left on the front-foot rolling to the medial side.

The ability of the golfer to keep a stable lower body in the backswing had a direct effect on the club head pathway in the downswing. If the golfer had too much lower body motion (32%) due to poor lower body control or lack of support in the backswing, the club bottomed out (hitting the ground) causing the clubface to make a poor contact with the ball. For some golfers this error resulted in heavy (hitting too much turf with the ball) and even thin shots (hitting too far up the ball). During the backswing a correct lower body motion (68%) had the hips turning a slight amount with the knees remaining near to their original fixed position and the space between them remaining constant.

Downswing

The objective of the downswing is to have the club-head arrive at the point of impact moving at maximum speed in the required direction and with the face of the club pointing in the same direction (Pforringer and Rosemeyer, 1989). The downward movement involved a rapid shift of weight from back to front-foot together with the forward motion of the golf club (Figure 2.10). Rotation started in the opposite direction to the backswing.

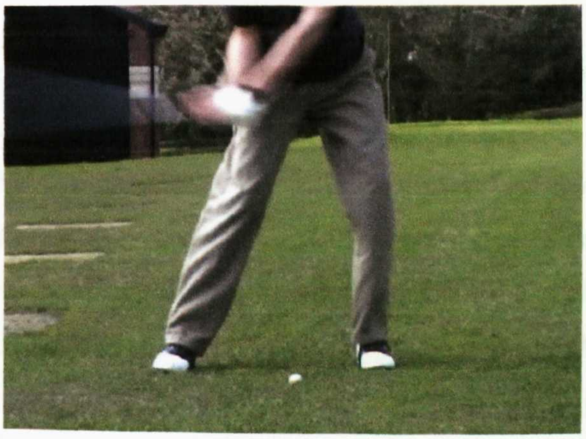


Figure 2.10. Weight Transfer onto the Left Foot during the Downswing.

The processes started in different ways dependant on the individual golfer. Three movement techniques were identified as the most common, a slide of the hips to the left (30%), a moving of the right knee in behind the ball (34%) and a transfer of weight from the medial side of the right foot to the lateral side of the left foot (36%). Some golfers used all three techniques at different times. Shot outcome was not consistently related to the three most common techniques or handicap. Figure 2.11 illustrates the three downswing movement techniques considered in relation to the type of shoe / spike worn.

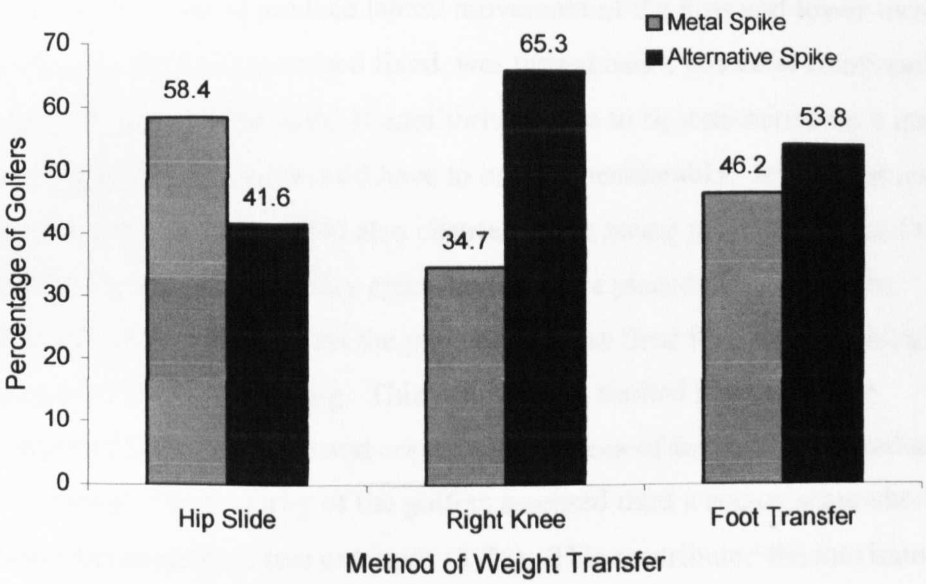


Figure 2.11. Spike Conditions used within Differing Methods of Weight Transfer.

The placement of the feet relative to one another and relative to the intended direction of the shot are of importance in determining the velocity with which the club-head meets the ball. Stance (how the feet are placed) had an essential role in determining the desired motion of the club-head in that it makes possible use of the entire body in the swing through weight transference from the back to the front-foot. As a result all the problems of stance and foot support are closely linked with the way golfers generate torque and forces to swing the club. The players who adopted a stance that allowed them to transfer the body weight from the right foot to the left generated torque and forces through Newtons Third Law of Motion 'for every action there is an equal and opposite reaction'. The players that adopted a stance that was too narrow or wide appeared to restrict the forces applied by the weight transfer and therefore the reactional forces, resulting in less powerful shots.

Maintenance of proper foot alignment before and during the backswing was a critical factor for control of the downswing and ball contact position. A number of miss-hit shots occurred due to poor foot alignment at address and into the swing motion. Foot alignment and stance was also important from the perspective of equilibrium. When the feet were placed too close together (6%), the narrowness of the base and restriction of foot movements appeared to inevitably make the golfer pay attention to the need to maintain balance. Such a restriction of foot movement and stance also prevented the full use of the legs as a source of power during the downswing. The foot movement is used to produce lateral movement of the hips and lower torso, which, if the pivot (foot) remained fixed, was turned into a powerful rotational movement of the arms and club. If equilibrium were to be maintained on a narrow base the length of the swing would have to be cut considerably. In contrast a stance with the feet too wide apart (8%) also obstructed the swing process. Beyond the width of the shoulders, the further apart the feet were placed, the greater the limitation of freedom with which the player could use their feet, legs and hips to generate power during the swing. This resulted in a limited rotation of the backswing and follow-through and consequently a loss of force from the reduced length of swing. The majority of the golfers assessed used a stance somewhere transitional between these two extremes (87%). This contributed the maximum stability possible without restricting rotation in either direction (backswing or downswing). Figure 2.12 illustrates the foot spacing sub-divided into the two spike types.

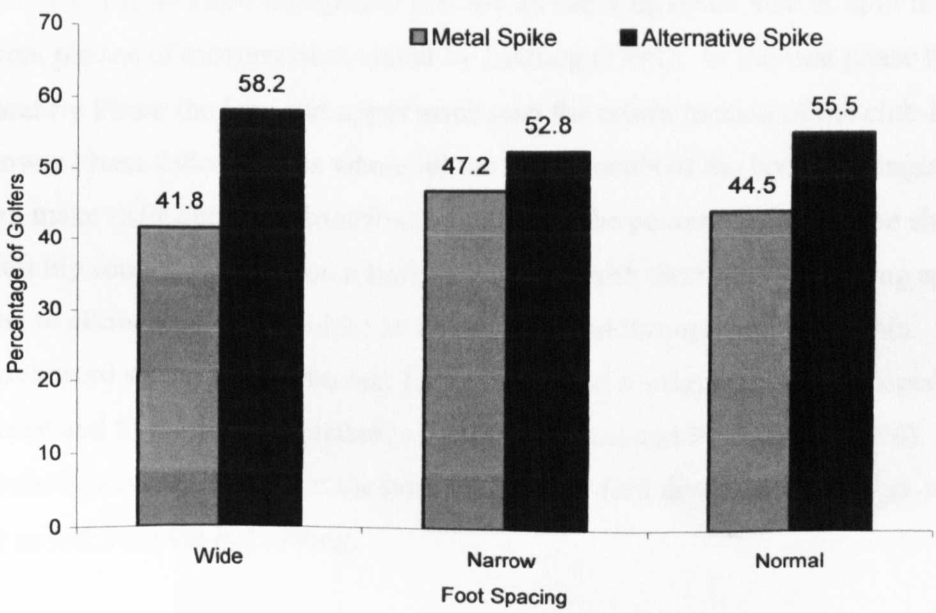


Figure 2.12. Foot Spacing During the Swing.

Through visual observation and monitoring of the angle of the feet at address it was identified that the majority of players had their stance relatively square to the line of the shot. A number of players however adopted slightly different positions. By having the right foot pointing at right angles to the line of flight the golfers were able to keep their weight on the medial edge of the rear foot in the backswing. In turn this prevented sway away from the ball. The right foot at right angles to the mid-line helped in keeping tightness of sequence on the backswing and forward swing into the ball. If the left foot was forward (closed stance), the path of the swing tended to move toward the right instead of straight ahead since the follow-through was restricted. Golfers who had their left foot pointing out slightly at address (more towards the target) encouraged a full transfer of weight to the left in the downswing, whilst a square stance aided in keeping the swing along this path. It is important to note that the angle of the feet at address is very individual and is often changed to correct common individual erroneous swing tendencies such as hooks and slices.

Within the more successful shots it was identified that the transfer of weight moved the shoulders slightly forward and flattened the vertical arc of the swing. This allowed more time in the swing during which the club-head could hit through the ball in the required direction.

Similar to Carlsoo's (1967) observation that the backswing could be broken down into two parts it was also recognised that the downswing could also be split into two different phases of movement as stated by Linning (1994). In the first phase the Preparatory Phase the legs and upper arms start the return motion of the club-head, the Power Phase followed this where all the components of the bodies swinging system make their optimum contribution to create the power needed for the shot. The left hip rotated virtually on a horizontal plane with the right hip dipping and turning to allow the right shoulder to drive down and through under the chin. During the downward swing phase, the rear foot everted and a valgus stress developed on the rear knee and first metatarsophalangeal joint (Thomas and Pietrocarlo, 1996). The downward momentum brought the heel of the front-foot down on the golfers who had it raised from the backswing.

At impact the golfer's centre of gravity moved forward of the midline between the feet, placing a greater proportion of the body weight on the left foot than on the rear. This was as a result of the weight transfer sequence during the downswing. At this time there seemed to be a continued valgus stress on the right knee and first metatarsophalangeal joint. This possible stress could be a result of the golfers' right shoes spike patterns and designs inhibiting the natural right foot twisting movement during the downswing and follow-through.

Only if the ball was contacted squarely was all the force available imported to the ball. If the ball was hit above the centre, some of the force pushes the ball into the ground rather than sending it forward.

Follow-through

The follow-through stage of the swing process does not have a direct affect on shot outcome. The golfer must however control the forces created during the follow-through and decelerate the swinging club and weight transfer. The reduction in force must be developed from the golfers contact with the ground through their feet / shoes and by applying muscular force against the club and body rotation. Any limitation in follow-through control increases the risk of injury to the golfer.

At impact the club travelled across the mid line between the feet towards the left hip, causing the hips to pivot in an inclined plane rapidly to make way for the hands and club inducing the body to rotate to face the target (Figure 2.13). The momentum of the club continued carrying the head on towards the target until the extended arms forced the club around and over the shoulders. This movement caused the right leg to rotate and the knee joint to flex and rotate medially until it came into close proximity to the left leg.

Figure 2.13. Rotation to the Left during the Follow-through.

The follow-though naturally caused a rolling of the back-foot to the medial edge and plantar flexion raised the heel and onto the toe. The front-foot moved often onto the lateral edge, in the worst case it hyper inverted causing a 'buckling' of the ankle (28%) in order to stop the forward momentum. This excessive transfer of weight through and beyond the golfers stance causes excessive strain on the lateral ligaments of the left ankle. The movement also reduces the amount of control and support the golfer has over the follow-through.

Proper weight shift was vital to creating the forces needed to control and hit a golf ball with power. The movements of the feet, knees and hips seemed to create and control such forces required for the shot. The higher handicapped golfers (15+) looked like they differed in the pattern and amplitude of forces generated during their swing (when compared to the medium and low handicap groups), due to the speed of the swing and body movements. They appeared to generate larger forces than the lower handicapped players but were unable to control these forces generated due to poor timing and control. Their swing involved a hurried incoherent movement from the top of the backswing down into the follow-through, generating maximum forces at the time when the body is least able to control them. The natural follow-through of the club often did not materialise, as the golfer had to apply large decelerations to the club to avoid injury. This open faced swing induced sliced shots.

Ninety-four percent of the golfers had their knees bent at impact. There was more hip rotation and knee movement in the downswing than in the backswing as a consequence there were more rocking motions. The knee movement patterns during the swing are shown below in figure 2.14.

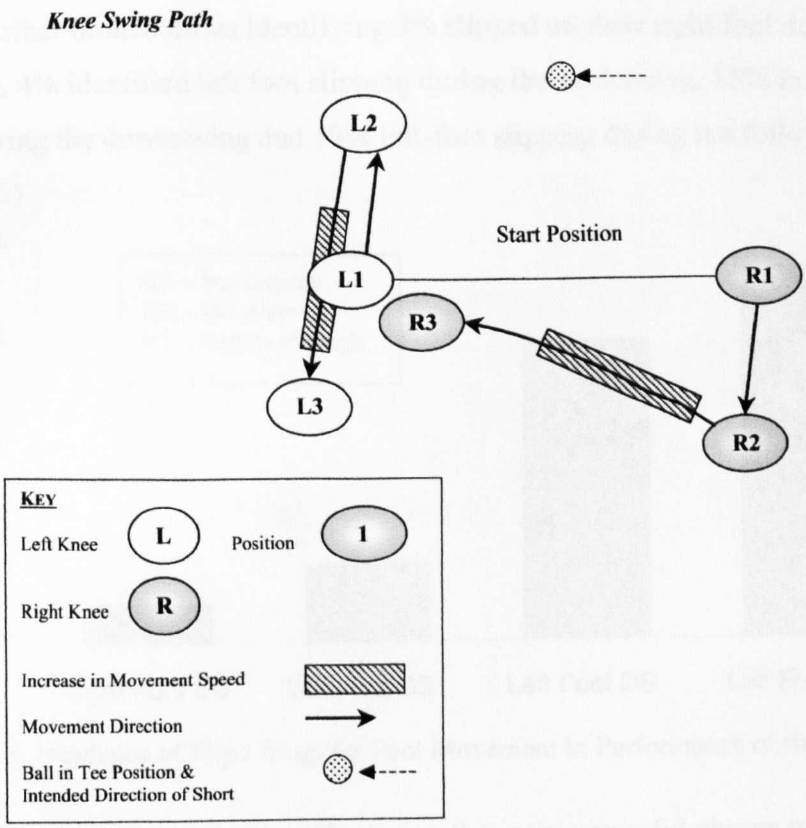


Figure 2.14. Knee Swing Path (Adapted from Linning, 1994)

At address the left knee and the right knee are positioned at L1 and R1. From the start of the backswing, through to the top of backswing L1 and R1 move through to L2 and R2 simultaneously. As the club moves down from the top of the backswing into the downswing and through into the follow-through L2 move to L3 and R2 moves to R3. The shaded rectangle areas on the figure identify the fastest more powerful movements of the knees. This movement occurs midway through the downswing through impact and into the first part of the follow-through.

Slipping

The forces exerted at the feet provided the foundation for the movements of the legs, trunk, and arms that occurred during the swing. Of the fifty-three participants 47% used spiked and 53% used alternative spiked shoes.

Only 60% of the golfers identified both feet being stable throughout their shot. Anything that interrupted the transmission of torques to the ground had an effect on movements in other regions of the body. This was highlighted when 40% identified slipping during the swing action.

This was further broken down identifying 2% slipped on their right foot during the downswing, 4% identified left foot slipping during the backswing, 15% left-foot slipping during the downswing and 19% left-foot slipping during the follow-through (Figure 2.15).

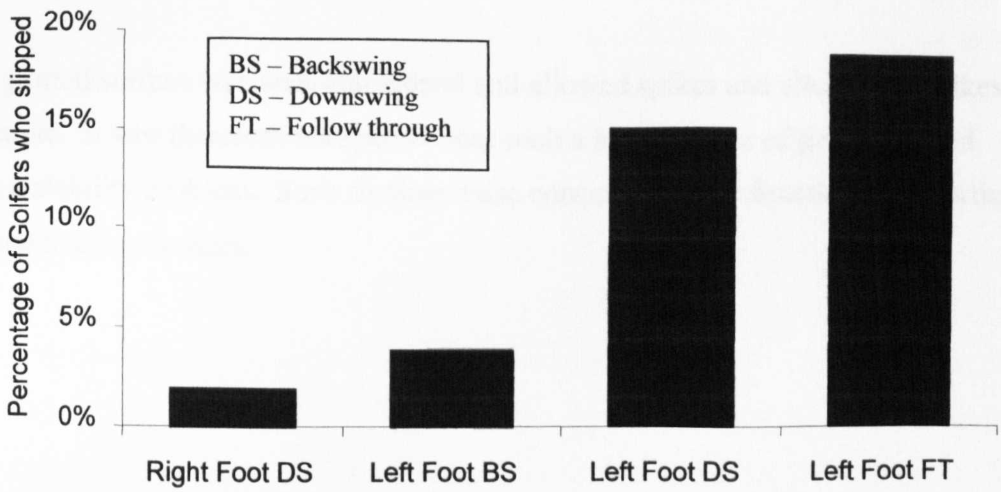


Figure 2.15. Incidence of Slip / Irregular Foot Movement in Performance of the Golf Swing

The loss of control was predominantly during the more powerful phases where greater forces were being exerted at the feet resulting in miss hit shots through poor ball contact or hooks and slices. The greatest amount of slipping occurred on the left foot/shoe emphasising the greater amount of forces or movements occurring on that foot. It was identified that 56% of the slips occurred when alternative spikes were worn relative to 44% when spiked shoes were worn.

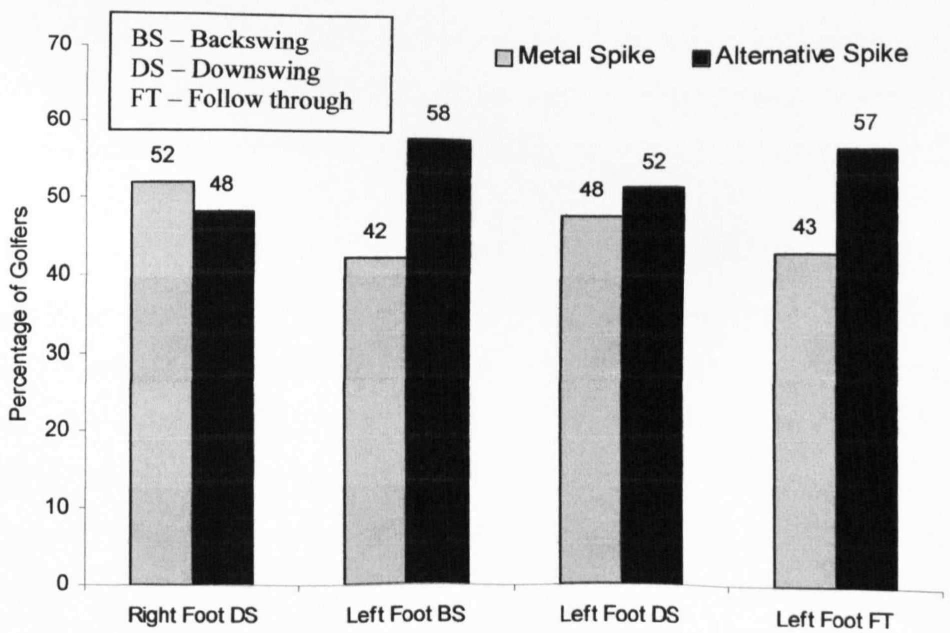


Figure 2.16 The Incidence of Slip or Irregular Foot Movement Relative to Shoe-Spike Worn.

Figure 2.16 shows the alternative spiked left shoe was associated with more slipping in the backswing, downswing and follow-through. It should be noted that a higher number of golfers wore alternative spikes (53%), compared to the traditional metal spikes (47%), which could influence these identified differences.

The ground surface was well-maintained and allowed spikes and alternative spikes to penetrate. It was therefore unexpected that such a high number of golfers would have a stability problem. Such findings raise concern over the functional properties of shoe traction devices.

2.5: Discussion

In the backswing a 'pressing' or 'cocking' motion was identified within 47% of the golfers. Within this motion the golfer slowly adducted the right thigh at the hip causing the right knee to move towards the left knee and then, as the knee returned to its original position, the withdrawal of the hands and club then followed. Similar findings were reported within the results of Carlsoo (1967) who suggested that this might serve to help the golfer initiate the backswing in a systematic and relaxed manner, but apart from this it would appear to have no particular merit in the swing performance.

During the backswing one of the critical elements was the constraint of the right knee, which was identified within the lower handicapped players. The players kept their right knee braced close to its address location during the backswing, putting the knees in position for the transition into the downswing. The knee constraint enabled the development of torque through rotation to the right around the axis of the centre of the leg creating a "wind up motion". The right leg movement depended on the stability, traction and frictional properties of the golfer's shoe. Without adequate traction and high frictional properties on the right shoe the development of torque was unlikely to occur. Linning (1994) observed this right knee characteristic in a study monitoring professional golfers, also suggesting that this movement ensured that the leg muscles which initiate the downswing, were pre-tensioned ready for the downward drive. Linning (1994) further identified that the right leg acted as a 'torsion buffer' that absorbed the angular momentum of the backswing as it decelerated to rest at the top.

In 1967, Carlsoo identified that the backswing could be divided into two consecutive parts – an accelerating movement backward and upward and a retarding or braking movement lasting until the top of the swing. This retardation was characterised by a change in the direction of the horizontal couple that the feet exerted against the ground and by marked changes in muscular activity. Carlsoo (1967) further identified that the activity of those muscles that had initiated the backswing, then diminished and that of their antagonists (those muscles that perform the opposite function) increased. Furthermore, the muscles that produced this retarding or braking effect on the backswing continued to be active during the downswing in which they acted as 'essential movement-promoting muscles.'

Completion of the backswing placed the weight on the right foot, which caused the shoe sole to invert (89%), evenly distributing the majority of the body weight between forefoot and rear-foot and the mid to lateral border, with the weight left on the front-foot everting to the medial side. The transfer of weight at this stage was suggested by Linning (1994) to be pushed to the right foot by the abductors and extensors of the left hip and knee while the extensors of the right leg kept the knee stable. Irwin, (1982) identified that during the backswing turn about 60 percent of the weight moves to the outside of the right foot as this encouraged a controlled sway away from the ball. The whole movement was initiated by body rotation away from the ball.

Through studying the golfers' body positioning from the top of the backswing down into the downswing it was likely that the golfers' bodyweight was transferred from the rear-foot to the front just prior to ball impact during the golf swing supporting Williams and Cavanagh (1983) and Cooper *et al.*, (1985). To get successful performance, golfers were required to co-ordinate the swing of the respective club to this transfer. As only the ground supports a player during the swing, the mediolateral ground reaction force is responsible for the shift of the body's centre of gravity toward the ball.

Throughout the golf swing into the follow-through proper weight shift was vital to creating the forces needed to control and hit a golf ball with power. The movements of the feet, knees and hips looked as if they created and controlled such forces required for the shot. By considering video recording in slow motion of the golf swing it was concluded that it is likely that the muscles of the legs and hips constitute to the main source of power in long driving. Williams and Sih, (1998) and Richards *et al.*, (1985) supported this stating that the legs and hips are actually the engine of the swing the arms and hands are the transport system.

At the time of the swing and primarily just before the contact of the club head with the ball, the left foot supports an insecure (unstable) stance with a simultaneous, limited, mechanical shifting of the foot and of the force from the medial to the lateral edge (Slavin and Williams, 1995). Pforringer and Rosemeyer (1989) suggested that this mechanical limitation can be explained by the predictable fact that many of the existing golf shoes were never designed for such a medial to lateral tilting motion, and thus the weight-bearing surface is totally inadequate.

Within this current study evidence was gained that slipping of the left foot during the back-swing, downswing and follow-through occurred when both traditional metal spikes and alternative spikes were worn.

2.6: CONCLUSION

The purpose of the study was to observe, collate and analyse typical lower limb movement patterns in the golf swing and to consider their relationship to different shoe sole interface designs worn.

The present study support the findings of Cochran and Stobbs (1968), Williams and Cavanagh (1983) and Slavin and Williams (1995) in identifying the importance of the foot and lower leg actions in generation of power, control and support throughout the swing. It also supported Williams and Sih, (1998) who suggested a successful swing was dependent on the performance of a complex sequential action involving the feet, knees, rotation of the hips and trunk that resulted in a appropriate transmission of forces between the feet and the ground.

The analysis identified the left and right foot functioned completely differently from one another and showed no symmetry. The right foot of a right-handed golfer performed a rocking movement during the swing, which at the end of the swing, the player movement first rested on the antero-medial edge of the forefoot and finally on the tip of the shoe. The demands placed on the right foot/shoe during the swing were relatively minor, requiring some support by having appropriately flexible movement.

The demand placed on the left foot / shoe were different and more demanding. There was a shift of weight from the medial to the lateral edge of the foot and inversion of the left foot in both the ankle and subtalar joints. In extreme cases this movement terminated in a hyper inversion “buckling” of the foot of almost 90 degrees and come to rest on the lateral edged of the foot, on the lateral edge of the shoe. This observation is in accordance with Richards *et al's* (1985) observation that

'The left foot supports a very labile equilibrium, i.e., an insecure stance with a simultaneous, limited, mechanical shifting of the foot and of the force from the medial to the lateral edge.'

The amount of inversion and eversion in each foot during the golf swing were asymmetric as weight shifted from right to left during the swing. During the backswing the left foot everted while the right foot inverted. During the follow-through the left foot inverted but the rear foot everted. It appeared that foot eversion was important in helping to keep the feet and lower body stable during the swing.

The degree to which the force produced by the body is transferred to the ball depends upon the reaction force from the ground against the feet. Ideally, golf shoes should make the movements of the lower extremity easier and provide a solid base of support. They should allow the engagement of appropriate muscular forces while simultaneously providing both increased ease and increased comfort. The interaction between the shoe and the ground is the link that allows the golfer to perform the body movements necessary during the golf swing and that culminates in the contact between that club head and the ball.

Good footwork cannot be built on an immovable, flat-footed base, or one on which the feet do not retain a controlling contact with the ground. To hit the ball solidly required steady controlled foot action. If the feet were unbalanced, then the entire upper torso over compensated with an exaggerated swing that resulted in a hook. The ball flew wildly as the body tried to recover its balance.

Through studying the foot movements of the 53 golfers it was possible to conclude that golf shoes, both metal and alternatively spiked, have been designed with minimal traction and support on the lateral edge of the left shoe resulting in insufficient traction. The shoes also do not provide adequate support (safety) during the natural rocking manoeuvre of the foot. If golf shoe designs were modified they could, within limits, contribute to the elimination of insecurity in the stance during the critically sensitive phase of the swing, and thereby permit more intensive concentration on the generation of movements in the upper extremities, the spinal column, and the hips to aid shot performance. The results of this study identify concern with regard to the amount of support and traction currently offered by golf shoes during the swing process.

Further detailed mechanical analysis of specific golf shoe spike designs and spike patterns will enable an understanding of the functional properties of traditional and alternative spikes and identify spike strengths and weaknesses.

Chapter 3: General Methodology

3.1: Golf Shoe and Spike Experimental Design Comparisons

Within this experimental thesis a traditional Adidas golf shoe with 8mm metal spikes was compared with three custom made Adidas alternative spike golf shoes (all with the same leather upper design) and a flat-soled golf shoe.

For the purpose of the experimental investigation the five different shoe designs were referred to using colour codes. The traditional shoe with metal spikes is described in figure 3.1 and was coded as Green. The three alternative spiked shoe designs and colour codes are shown in figures 3.2, 3.3 and 3.4. The flat-soled shoe, coded as black, is shown in figure 3.5.

All shoes incorporating spikes used the 'Fast Twist Insert System' in order to attach to the shoe sole and were available in UK sizes 8½, 9½, 10½. All shoes were new to avoid the chance of sole / spike degradation or wear characteristics influencing the experimental outcome. These golf specific shoes were also compared to a pair of flat-soled shoes assessed without any golf specific traction.

Figure 3.1. Green Shoe Condition.

- Adidas 'Stripe Tournament' Sole.
- TPU Out-sole, EVA Mid-sole
- Full Grain Leather Upper
- Full Grained Leather Lined
- Fast Twist™ Traditional 8mm Metal Spikes

Figure 3.2. Red Shoe Condition.

- Adidas 'Stripe Tournament' Sole.
- TPU Out-sole
- EVA Mid-sole
- Full Grain Leather Upper
- Full Grained Leather Lined
- Fast Twist™ Alternative Adidas Spikes

Figure 3.3. Blue Shoe Condition.

- Adidas 'Tour Traction Competition' Sole.
- EVA Mid-sole
- Full Grain Leather Upper
- Full Grained Leather Lined
- Fast Twist™ Alternative Adidas Spikes

Figure 3.4. Yellow Shoe Condition.

- Adidas 'Z-Traction Tour' Sole.
- TPU Out-sole
- EVA Mid-sole
- Full Grain Leather Upper
- Full Grained Leather Lined
- Fast Twist™ Alternative Adidas Spikes

Figure 3.5. Black Shoe Condition.

- Stylo Adapted 'Flat' Sole
- EVA Mid-sole
- Full Grain Leather Upper
- Flat Sole Bed

3.2: Force-platform Set-up

Ground action forces were measured using a Kistler 9851B Force Platform(s) (Kistler instruments Ltd). The force platform data was passed to a Kistler 9865 amplifier and converted to digital format using an Amplicon 12-bit converter. Kistler Bio-Ware 3.1 software running on an IBM computer controlled data sampling at 1000Hz and recording of the data to hard disk for subsequent analysis.

The force-plate was covered in a natural grass surface, similar to that found on a teeing off area on a golf course. The turf was attached to a clay plate, which was screwed onto the top of the force platform (Janaway and Dyson, 2000).

The force platform horizontal plane offset was adjusted to 35mm to reflect the depth of the turf-covered plate.

Grass surfaces were exposed to the same water, light and humidity conditions prior to testing to minimize differences in turf conditions. To maintain consistency between grass plate moisture levels were assessed using a moisture-testing probe (Rapitest). Turf was rated on a scale between 1 and 4, with 1 classed as dry and 4 wet. All turf samples used in the thesis were rated at level 2 allowing shoe spikes to penetrate the surface without the shoe sole sinking into the surface.

CHAPTER 4: THE MEASUREMENT OF MODERN GOLF SHOE TRACTION PROPERTIES

4.1: INTRODUCTION

A primary goal of golf shoe outsole design is to minimise the possibility of slip between the shoe and ground. While traction has traditionally been achieved by using relatively long metal spikes, recent designs have included moulded projections on the outsole in addition to spikes (Slavin and Williams, 1995)

During the backswing, as a result of muscle activation, a right-handed golfer applies a large shear horizontal (Fy) force directed in the anterior direction on the left foot and in the posterior direction on the right foot. In the downswing and follow-through the golfer applies large forces in the posterior direction on the left foot and in the anterior direction on the right foot. The asymmetrical force generation between the feet has been identified as 'coupling of the feet' (Worsfold *et* al., 2002). The ground resists these latter forces by applying equal and opposite forces via the spikes or frictional forces between the ground and outsole. The ratio of the torque and shear forces to vertical force is typically highest during the downswing before ball contact (Williams and Cavanagh, 1983), if this torque and shear force exceeds the traction interaction between the shoe sole and ground surface then slip occurs. Any slipping during the swing may adversely affect shot performance (Slavin and Williams, 1995).

Friction between two surfaces in contact is determined by the resistance of these two surfaces to the relative movement (Nigg, 1989). Friction between different shoes and surfaces relates to the static and dynamic frictional coefficient (Frederick, 1986). Friction can also be subdivided into translational and rotational friction components. Translational refers to a repositioning of the whole foot, as in sliding; and rotational, refers to a rotation of the foot around a point of contact on the shoe sole. The translational friction coefficient was assumed to depend on the material and the structural pattern of the two surfaces, and the relative velocity between the two surfaces. Rotational friction characteristics can be assessed by measuring the moment of rotation with respect to an axis through the instantaneous center of rotation (Nigg, 1989). Nigg identified that there is no well-defined correlation between the resistance to translational and rotational movement. Tests using a rotational test movement might produce results different from tests that use a translational movement. It is therefore necessary to study the translational and the rotational traction characteristics of a surface-shoe combination in order to describe the tractional properties of a system. During the follow-through, in a right-handed golfer the traction characteristics of the golf shoe must allow an anti-clockwise rotational movement of the rear shoe's forefoot. During the golf swing no translational shoe movement during the swing should occur in either foot, this would only be observed when slipping occurs.

It is possible to gain a detailed biomechanical analysis of the dynamic forces acting at the shoe surface interface during an actual golf swing using force platforms. To aid accurate mechanical comparisons shoes should be subjected to repeatable forces in directions specific to the natural golf swing. Appropriate mechanical traction testing will aid comparisons between different golf shoe sole interface designs identifying specific shoe traction properties. Such analysis allows evaluation of traction performance within a controlled, repeatable environment.

4.2: Literature Review

Frederick (1986) identified that one prominent pattern emerging from the literature on sport shoes and biomechanics is the observation that many effects are the indirect result of shoe-induced adjustments in movement, (i.e. a particular shoe characteristic elicits a kinematic adaptation, which in turn has secondary consequence on kinetics).

Little research has examined the mechanical properties associated with traction of golf footwear on natural surfaces. As a result a complete understanding of the complex interactions between the leg, foot, footwear and the surface has not yet been achieved and as a consequence, precise footwear design criteria to improve golfing performance and safety have yet to be established.

Past shoe traction measuring systems and research have focused on other sports shoes. Bonstincl, *et al.,* (1975) studied shoe friction torques developed during different leg impacts on various playing surfaces. Eleven different American football and sports shoes were tested on grass and three different artificial surface, while the energy of impact was varied. Strain gauges were mounted to the ground surface, which monitored the "effective" torque developed at the shoe surface interface. A weighted pendulum was swung into the leg construction to simulate a player's leg receiving instantaneous torque. All tests were performed under dry surface conditions. It was found that the torque developed by spiked shoes on synthetic turf was highly related to the total effective cleat surface area. The total effective cleat surface area was defined in this study as the number of spikes (or proportionate part) actually in contact with the synthetic surface area on the bottom of each of the spikes. The non-spiked shoes developed torque as a result of frictional contact between the outsole of the shoe and the playing surface. The non-spiked shoes consistently developed less torque on natural grass than on any synthetic turfs. Furthermore, differences in torques resulting from variations in outsole design and composition among the non-spiked shoes appeared to be minimal on any particular surface.

Barry and Milburn (2000a) tested the traction properties of football boots on grass. Each boot was fixed to a shaft and lowered to touch the grass surface. While in this position a transducer (Sakae) was positioned to measure the vertical displacement and a Kistler force plate was used to measure the traction force. The shaft was free to move as the device slid the boot horizontally over the surface. A 35 kg mass was used to represent half body weight through each leg, producing a total load (weights + shaft) of about 400 N, representing a total body weight of 800 N, a value used by Schlaepfer *et al.*, (1983) and Beard and Sifers (1993) in related research.

Barry and Milburn (2000b) tested five different grass surfaces varying in moisture contents, using four different football boots (two studded and two bladed). Each boot was tested for braking traction involving a forward motion from heel to toe; propelling traction where the motion was backward; and two sideway tractions, where the boot's long axis (heel to the toe) was rotated at 45° and 135° to forward motion. Precise sliding and angular displacements were applied to the vertical shaft and boot by a sliding plate connected to a small thread shaft rotated by a step motor. The study identified each boot developed different traction forces on each of the surfaces tested. The bladed boots "developed a larger traction at 45°". Although the research studied football boot traction, the main results were based around the ground surfaces tested.

Slavin and Williams (1995) reported the first traction study focusing on golf shoes. They tested the traction coefficients of nine spiked shoe sole configurations and a flat-soled shoe. Shoes were placed on a grass covered Kistler force platform. A load of 37kg (approx 0.4 typical body mass) was applied to the forefoot region of the shoes with the load based on measurements of the shear / vertical force ratio during a typical swing. A wheel cart system was used to create a vertical load, which incorporated minimal rolling resistance.

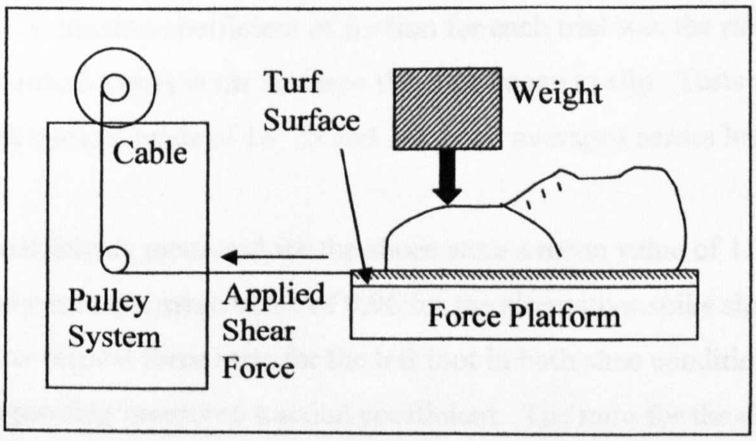


Figure 4.1. Slavin and Williams (1995) Wheel Cart Traction Measuring System.

The maximal static coefficient of friction for each trial was identified as the ratio of horizontal to vertical force at the instant the shoe began to slip. A mean value from the eight trials within each condition was collected. The smooth sole offered significantly lower coefficient of friction (0.73) compared to the other nine spiked shoes tested. The traditional 8mm spike was identified to offer the highest coefficient of friction (1.48). The incorporation of spikes, and use of a longer spike significantly improved linear traction on a normal grass surface. Alternative spike designs, alone or in combination with shorter than usual spike lengths, provided greater traction than a flat soled shoe but less traction than a shoe with traditional spikes. The shoes incorporating non-traditional or moulded spike configurations appeared to result in a higher probability of slipping.

Williams and Sih (1998) further tested the traction coefficients of three different regular-spike, a flat-soled shoe and three alternative-spiked golf shoes. The shoes tested incorporated traditional 8mm spikes, alternative spikes and a smooth sole. The shoes were placed on an "artificial surface" that was attached to a force platform, and a shear load was applied using a high torque, fixed-gear motor that applied a set velocity pull through a cable to a bolt mounted in a shoe last placed in and projecting out from the shoe. The pull was applied to the left shoe in a backward direction in the horizontal plane along the long axis of the shoe to mimic the orientation of the force vector seen during the downswing of a right-handed golfer. Static coefficient of friction, termed the traction coefficient, was determined for each type of golf shoe. Vertical and shear forces were recorded at 200 Hz while the load was applied. The traction coefficient of friction for each trial was the ratio of horizontal to vertical forces at the instance the shoe began to slip. Tests were performed with vertical loads of 14, 25 and 36kg and averaged across loads.

The traction coefficients measured for the shoes were a mean value of 1.38 for the regular-spike shoes and a mean value of 0.96 for the alternative-spike shoes. The average shear to vertical force ratio for the left foot in both shoe conditions was less than the corresponding measured traction coefficient. The ratio for the right foot became higher than the traction coefficient at or just following ball impact and in many trials the right foot moved slightly following impact. It is at this point where the transfer of the golfer's bodyweight moves from the back-foot (right) to the front-foot (left). The higher ratio identified within the right foot would not cause any detrimental effects on the swing performance. The body weight is rapidly transferred onto the left foot, which then supports and controls the golfing movements. The right foot is only used as a means of balance at this stage and rotates anti-clockwise onto the medial forefoot soon after ball impact.

The traction coefficient of the smooth leather sole was 0.39, much lower than for the regular spike or alternative-spike shoes. It was identified that the shear / vertical force ratio for the smooth leather sole followed a similar pattern to that of the alternative-spike shoe until approximately 0.2 seconds before ball impact, at which time the ratio for the smooth-sole shoe leveled off and slip of the shoe occurred, as indicated by the sharp change in horizontal (x and y) displacement patterns. The data provided some initial evidence that the ratio of shear to vertical force relative to the traction coefficients is important in determining whether or not slip occurs. The results may be observed with reservation when evaluating the performance of the shoes during the golf swing, as an 'artificial surface' (not described) was used to represent grass which may give an unrealistic evaluation.

Frictional resistance must be within an effective range (Milburn and Barry, 1998). If the frictional resistance were too low, slipping would occur which would cause adverse performance during the shot. Equally excessive friction would not allow the shoe to 'give' causing the shoe and ankle to buckle during uncontrolled, unbalanced shots. During the follow-through the natural motion of the swing causes the rear foot to rotate anticlockwise onto the medial toe in line with the motion of the swing. It is therefore important that the shoe's traction should allow this movement without impeding it. Excessive friction on the front-foot from the point of impact and through the follow-through may be the result of the front-foot 'buckling' as a result of the dramatic weight transfer onto the foot as identified in previous studies (Worsfold *et al.*, 2002). Such an aggressive weight transfer onto the lateral edge of the ankle may cause acute injury and impair the shot outcome. In contrast insufficient traction will cause the foot to slip also resulting in possible injury and poor shot outcome.

This review has identified that it is possible to analyse the traction properties of individual shoe sole interface designs through using a mechanical traction test. Such traction testing allows controlled and repeatable forces to be applied to the shoe designs specific to forces produced during a golf swing. It is then possible to evaluate between shoe sole interface designs and identify specific sole strengths and weaknesses. The resulting force information in conjunction with dynamic swing performance analysis would give a detailed understanding of the shoe ground interaction. The limited past golf shoe research has predominantly used force platforms covered with artificial surfaces to measure the traction of golf shoes. As a result it is not possible to relate these findings with actual shoe performance on natural grass. Past studies have used motor controlled wheel cart systems to apply directional force to the shoe. Such systems produce a constant force to the shoe, however the motor does not apply a gradual initial force. As a result the force applied would be immediate jolting the shoe, increasing the probability of initial slipping. The golf swing requires clockwise and anticlockwise rotations throughout the swing process. Such rotations are created at the golfers feet, the golfers only point of contact with the ground. As a result golf shoes are required to generate and control such rotational forces. However no reported rotational traction test studies have been reported, limiting the understanding of golf shoe functional traction.

Further linear and rotational mechanical traction assessment of different shoe sole interfaces (flat, alternative and traditional) using natural grass covered force plates along with gradual applied forces is required to gain an accurate analysis of the soles functional properties.

4.3: Aim

The aim of the present study was to test and compare the linear and rotational forefoot and whole-foot traction properties of five modern golf shoes varying in spike pattern and sole design. Through using a shoe traction measuring system, the study aims to identify which shoe sole interface produced the best traction performance.

4.4: Hypotheses:

H_{01}: No differences in linear action forces will be identified between shoe conditions.

H_{1a}: Traditional metal spiked golf shoes will produce higher linear action forces when compared to a flat-soled golf shoe.

H_{1b}: Alternative spiked golf shoes will produce higher linear action forces when compared to a flat-soled golf shoe.

H_{1c}: Traditional metal spiked shoes will produce higher linear action forces when compared to alternative spiked shoes.

H_{02}: No differences in rotational action forces will be identified between shoe conditions.

H_{2a}: Traditional metal spiked golf shoes will produce higher rotational action forces when compared to a flat-soled golf shoe.

H_{2b}: Alternative spiked golf shoes will produce higher rotational action forces when compared to a flat-soled golf shoe.

H_{2c}: Traditional metal spiked shoes will produce higher rotational action forces when compared to alternative spiked shoes.

H_{03}: No differences in limiting friction forces will be identified between shoes.

H_{3a}: Traditional metal spiked golf shoes will produce higher limiting friction forces when compared to a flat-soled golf shoe.

H_{3b}: Alternative spiked golf shoes will produce higher limiting friction forces when compared to a flat-soled golf shoe.

H_{3c}: Traditional metal spiked shoes will produce higher limiting friction action forces when compared to alternative spiked shoes.

4.5: METHOD

Five left foot golf shoes of different designs were assessed. Shoe design details were described in section 3.1. The testing incorporated only the left shoe in each condition as the right and left shoe designs in each condition were symmetrical. The test applied forces in the direction identified within the left foot when performing as a front-foot (right handed golfer). The same shoe was then assessed using the forces identified within the back-foot, as would be identified within a left-handed player where the left shoe would be the back-foot. The shoes were tested with the sole interface flat on the ground (whole-foot) and also with only the forefoot of the shoe on the ground. The two different shoe placements were representative of the shoe positions during different stages of a golf swing, identified within chapter 2. The shoe test order was systematically rotated throughout.

Figure 4.2 shows the shoe last attached to a metal leg strut, which allowed weights to be added. This was then connected to a free moving joint at the top and mounted to a frame as shown in figure 4.3.

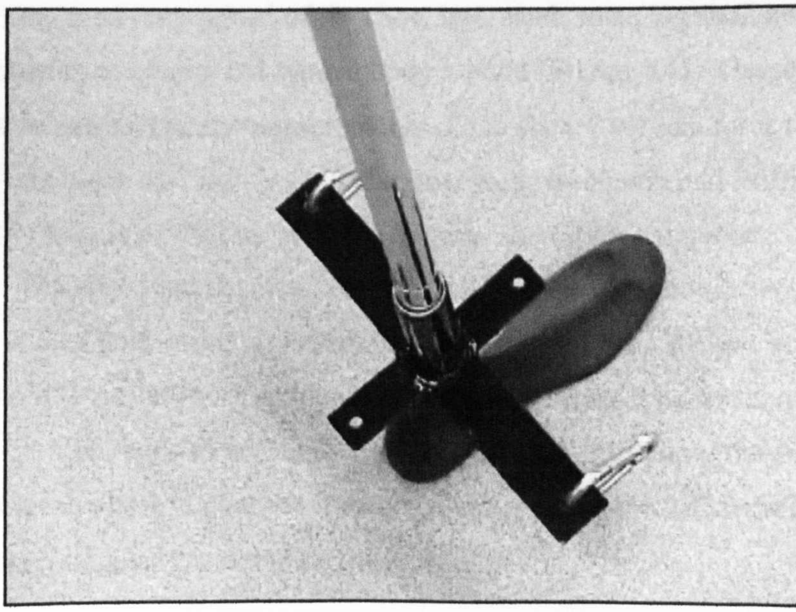


Figure 4.2. Metal Shoe Last, Fixed to a Metal Leg Strut, with a Metal Cross Fixing Allowing Various Forces to be applied.

A sock was fitted around a metal last. This sock was filled with sand to pack the shoe allowing close-fit with the shoe. The golf shoe under test was put on over the sock and the shoelaces tied, as they would be around a golfers foot. Each shoe type, which underwent testing, was a UK shoe size 9. The leg structure was free to move in any direction required.

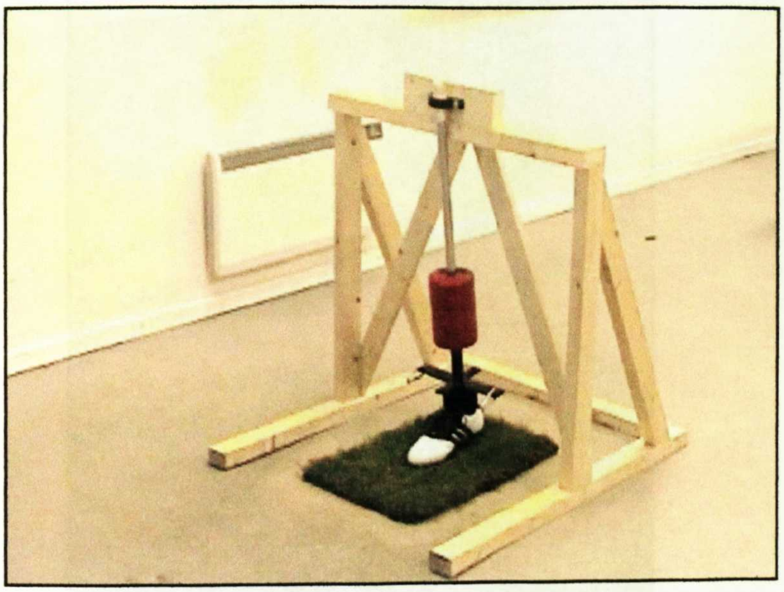


Figure 4.3. Leg Mounted to a Frame Situated Over the Grass Covered Force Plate.

The traction test leg design was based on Slavin and Williams (1995) traction study utilising a 37kg load (comprised of the shoe, last, sand, sock, leg shaft and selected weights) equating to approx 0.4 typical body weight (Figure 4.4). The selected weight was determined using measurements of the shear / vertical force ratio during a typical swing identified within a comparative study by Slavin and Williams, (1995). The position of the load on the shoe was altered for a number of different conditions. The shoe load positions were determined by the relevant weight positions during a golf swing, as recognised within chapter 2. Weight was loaded onto the whole foot (flat foot), as identified during the stance, backswing and downswing in both feet and within the front-foot during the follow-through. The 37kg load was also placed over the forefoot of the shoe, as identified during the follow-through stage of the swing on the back-foot.

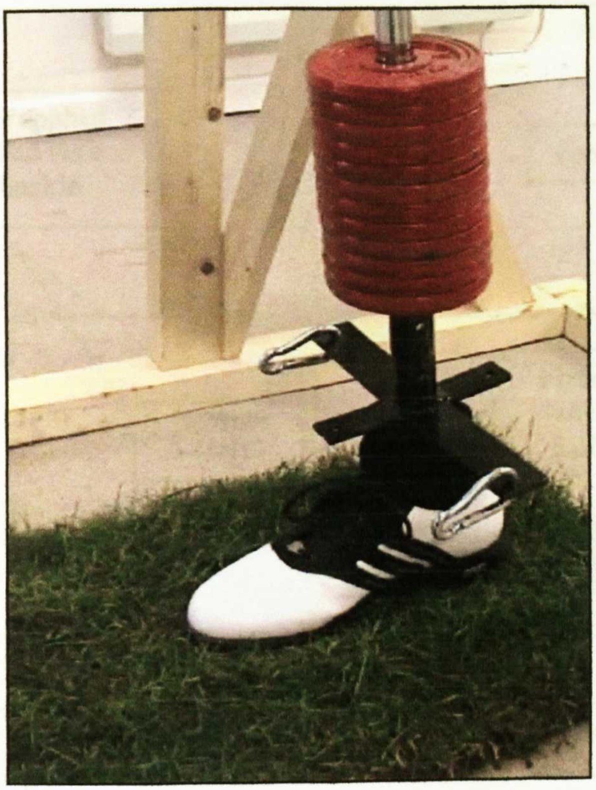


Figure 4.4. Shoe Attached to the Leg With Vertical Load Applied.

Experimental method at the shoe-surface interface:

The forces were produced through applying a constant force to the testing leg/last located on a grass surface. The forces were applied by manually pulling on a shackle attached to the leg shaft. The force applied was maintained as constant as possible so not to jolt the shoe. Anterior and posterior forces were produced by connecting, and applying a constant force to the shackle fixed to either the bracket situated above the toe or heel of the shoe. Inward and outward rotational forces were applied by attaching the shackle to either the medial or lateral cross bracket. Eight repeat trials were collected for each shoe condition.

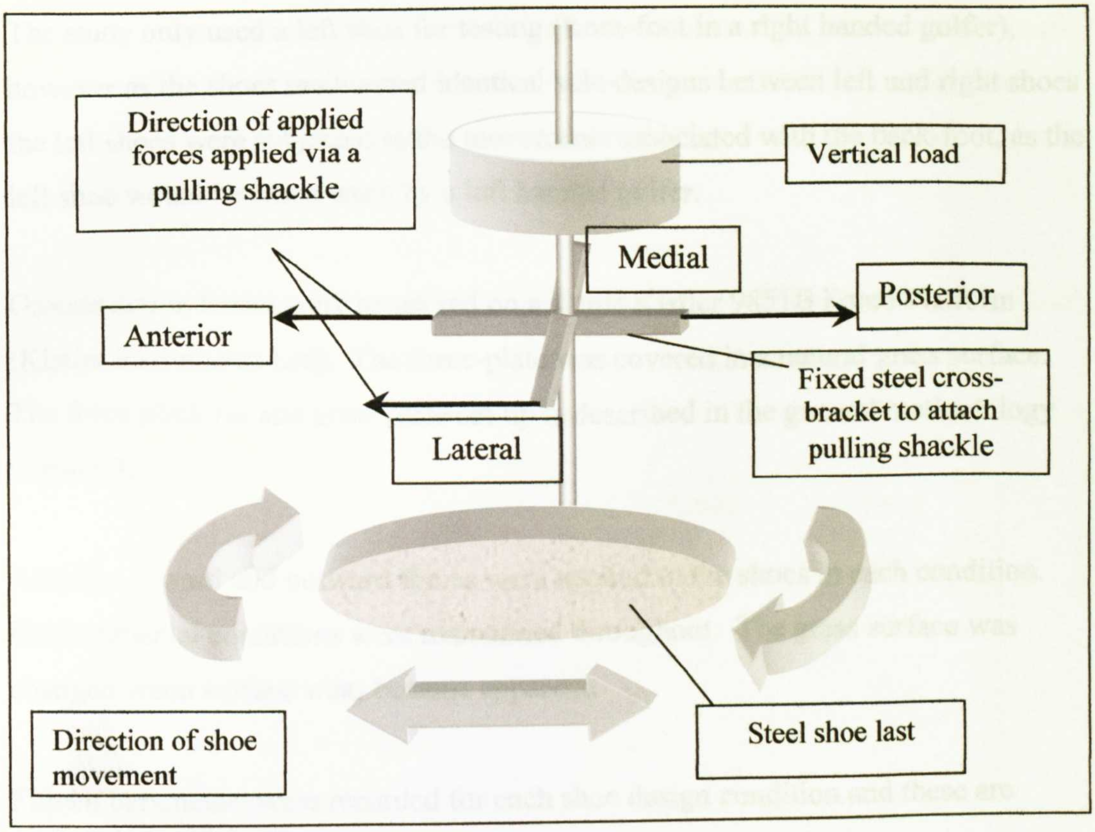


Figure 4.5. Diagram Identifying Points of Rotation and Applied Forces (Diagram not to scale).

Medial and lateral forces were applied to the shoe last resulting in inward (heel rotating left) and outward rotations of the shoe (heel rotating right) (figure 4.6). No outward forefoot measurements were tested, as this movement on the forefoot is not produced during an actual golf swing.

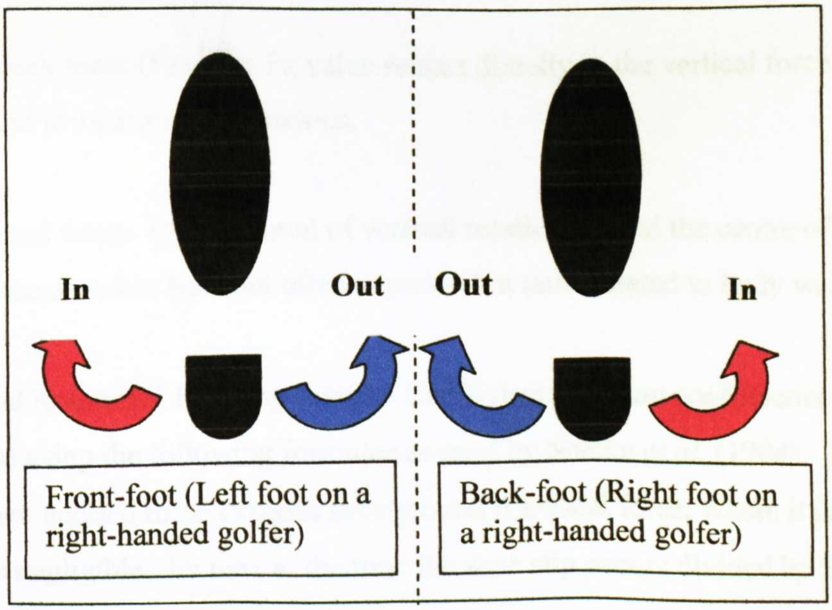


Figure 4.6. Diagram Identifying Inwards and Outward Shoe Rotation

The study only used a left shoe for testing (front-foot in a right handed golfer), however as the shoes maintained identical sole designs between left and right shoes the left shoes were subjected to the movements associated with the back-foot, as the left shoe would be when worn by a left handed golfer.

Ground action forces were measured on a single Kistler 9851B Force Platform (Kistler instruments Ltd). The force-plate was covered in a natural grass surface. The force platform and grass plate set-up is described in the general methodology chapter 3.2.

Anterior, inward and outward forces were applied to the shoes in each condition. Environmental conditions were maintained throughout. The grass surface was changed when surface wear became apparent.

Fifteen parameters were recorded for each shoe design condition and these are summarised below and in tables 4.1 and 4.2.

Horizontal shear force (Anterior / Posterior force, Fy): The horizontal shear force is a measure of anterior and posterior forces measured in Newtons (N) that are associated with the golfers rotational movements. The force is created through the golfers feet 'coupling' in opposite anterior and posterior directions to create both inward and outward rotations.

Vertical peak force (Fz): The Fz value relates directly to the vertical force applied to the feet and is measured in Newtons.

Tz rotational force: Free moment of vertical rotation around the centre of pressure, which is measured in Nm (but often expressed in units related to body weight)

Linear and Rotational Limiting Friction Coefficient: Friction coefficients were calculated using the following formulae as used by Stucke *et al.* (1984). The force value when applied force exceeds shoe ground frictional force, where it is assumed that Fx is negligible. Fy max at the time the shoe slip occurs divided by Fz at the time shoe slip occurs = Limiting Linear Friction.

Rotational Limiting Rotational Friction Coefficient: The value when applied torque exceeds shoe ground frictional force, where it is assumed that Fx is negligible.
Tz max at the time the shoe slip occurs divided by Fz at the time shoe slip occurs = Limiting Rotational Friction.

The maximal static coefficient of friction for each trial was identified as the ratio of horizontal (Fy) to vertical force (Fz) at the instant the shoe began to slip.

Forefoot

Variable	Inward Rotation	Linear
Limiting Friction	√	√
Maximum Vertical Fz	√	√
Maximum Torque Tz	√	×
Maximum Anterior Fy	×	√

(√ Identifies measure tested × Identifies measure not tested)
Table 4.1. Forefoot Variables Measured.

Whole foot

Variable	Outward Rotation	Inward Rotation	Linear
Limiting Friction	√	√	√
Maximum Vertical Fz	√	√	√
Maximum Torque Tz	√	√	×
Maximum Anterior Fy	×	×	√

(√ Identifies measure tested × Identifies measure not tested)
Table 4.2. Whole Foot Parameters Recorded.

Data analysis:

Line graphs were produced from the Bio-Ware 3.1 software. From the graphs it was possible to identify the point at which point slipping occurred (Figure 4.7) and points of rotation (Figure 4.8). Descriptive statistics were calculated and tabulated. Sphericity was assessed using Mauchly's Test to identify if variance of differences between conditions were equal. If sphericity was not assumed, Greenhouse-Geisser corrections were used. Data were analysed using a one-way ANOVA (shoe) with repeated measures. Significant differences ($P<0.05$) were then detected by Post Hoc Tukey HSD tests.

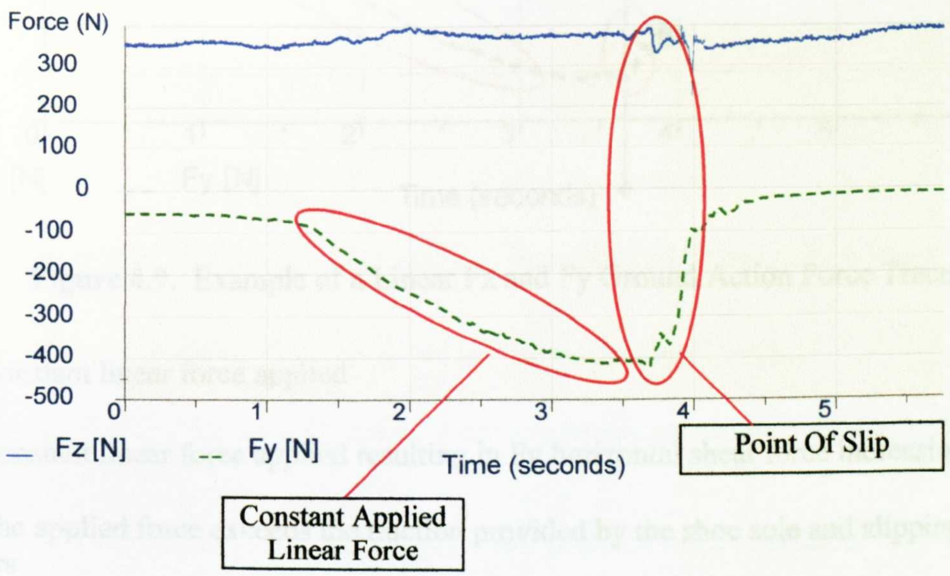


Figure 4.7. Example of a Horizontal Shear (Fy) and Vertical (Fz) Force Trace.

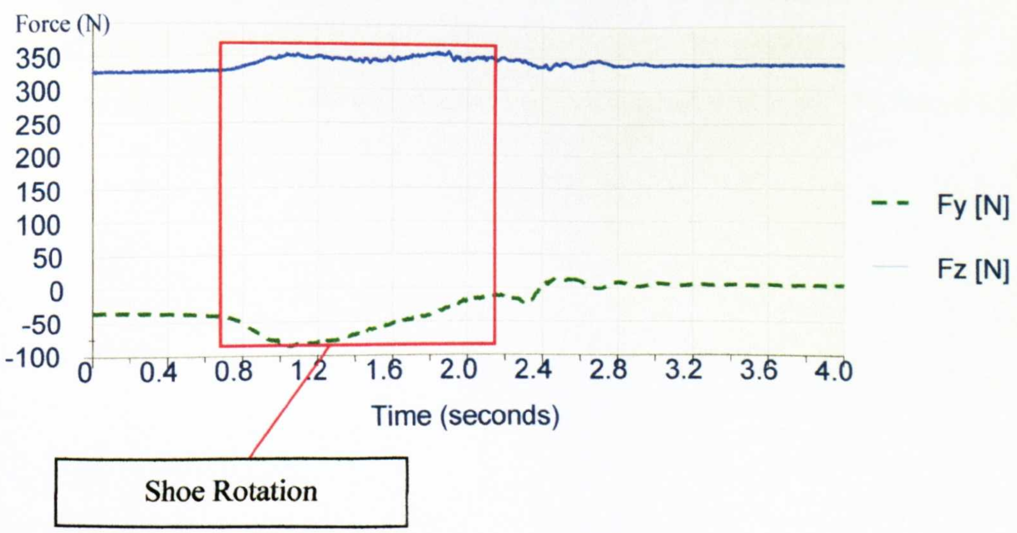


Figure 4.8. Example of a Whole-foot Outward Rotation Trace.

4.6: Results

Figure 4.9 shows an example Fy and Fz ground reaction force trace of a linear whole foot trial.

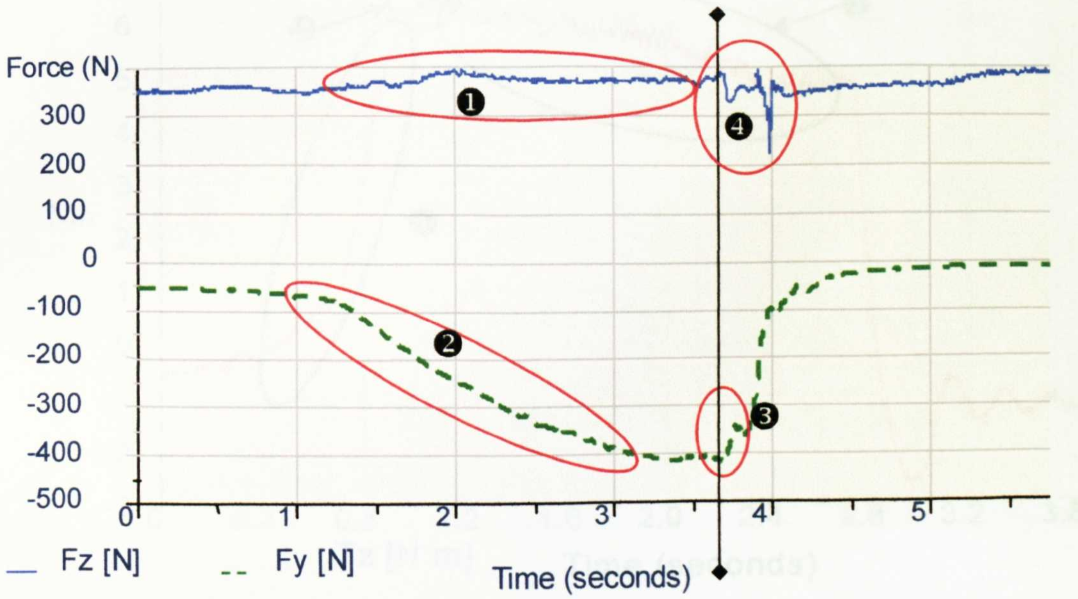


Figure 4.9. Example of a Linear Fz and Fy Ground Action Force Trace.

❶ Constant linear force applied

❷ Constant linear force applied resulting in Fy horizontal shear force increasing.

❸ The applied force exceeds the traction provided by the shoe sole and slipping occurs

❹ Applied force exceeds the traction provided by the shoe sole and slipping occurs.

Figure 4.10 shows an example of a Tz forefoot ground reaction force inward rotation trace.

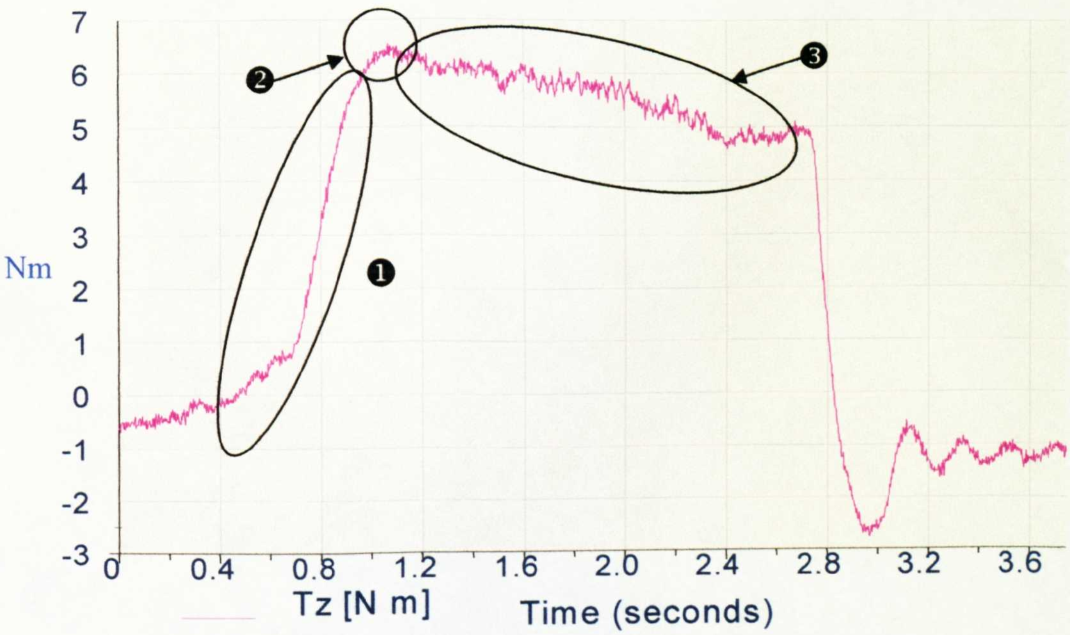


Figure 4.10. Example of a Rotational (inward) Tz Ground Action Force Trace.

❶ Rotational force applied to the shoe / last increasing the Tz value.

❷ The applied force exceeds the shoe's traction at approximately 1 second and the shoe starts to rotate.

❸ The shoe continues to rotate (inward) as the constant force is applied.

Mauchly's Test of sphericity identified that the variance of differences between conditions were not significantly different, as a result a Greenhouse-Geisser adjustment was not required. Parameter descriptive statistics are shown in the following tables. Individual measurements composing mean data are in appendix B.

Linear Forefoot

Shoe	Fz (N)	SD	SE	Fy (N)	SD	SE	Limiting Friction
Yellow	373.19	3.30	1.17	338.30	4.91	1.74	0.91
Blue	368.08	6.76	2.39	337.35	3.38	1.20	0.92
Green	370.06	3.62	1.28	358.96	4.89	1.73	0.97
Red	368.29	4.13	1.46	333.77	5.53	1.96	0.91
Black	366.72	5.10	1.80	243.01	4.52	1.60	0.66

Table 4.3. Mean Linear Forefoot Results
(Note: values are at the point slipping occurred within the shoe condition).

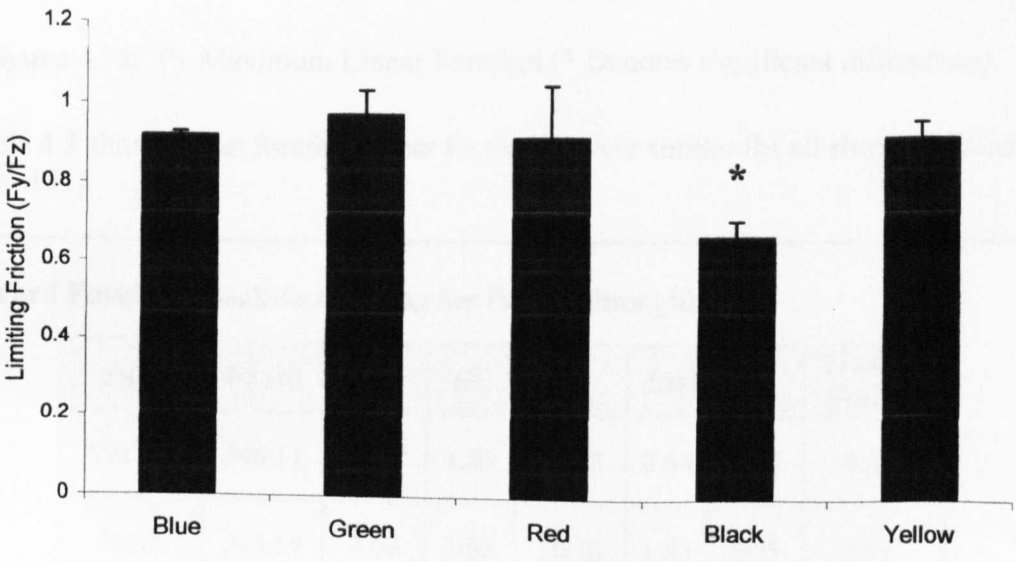


Figure 4.11. Linear Forefoot Limiting Friction (* Denotes significant difference).

The Black shoe incorporating a flat-sole design produced significantly less linear forefoot limiting friction when compared to all other shoe conditions $F(4,28) = 20.13$, $P = <.05$. The results support H_{3a} and H_{3b}, highlighting the limited forefoot traction of the flat-soled Black shoe when compared to shoes with additional traction.

Linear Forefoot Fy Maximum:

The black flat-sole shoe condition was identified to be significantly different (F(4,28)

= 698.32, P = <.05) to all other shoes supporting H_{1a} and H_{1b}. The traditional metal spiked Green shoe condition was also found to be significantly greater than all other shoes, supporting H_{1a} and rejecting H_{01}.

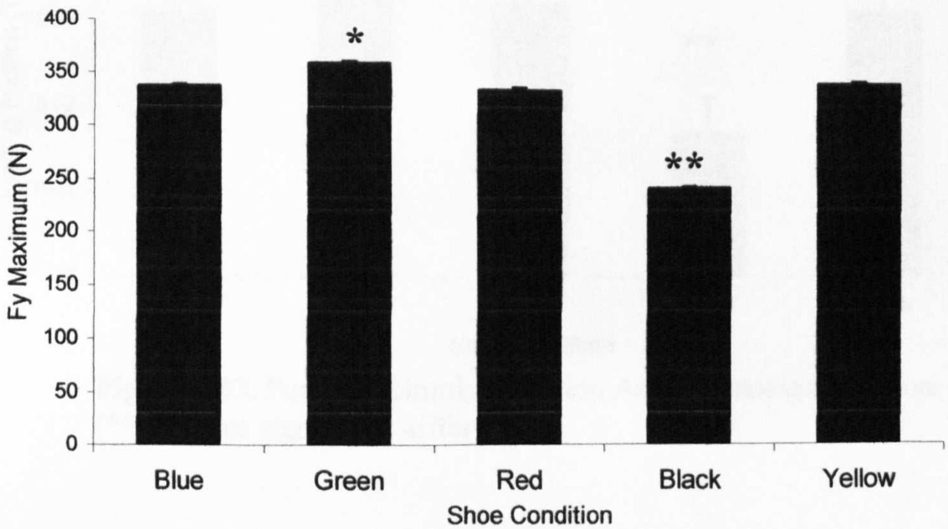


Figure 4.12. Fy Maximum Linear Forefoot (* Denotes significant differences).

Table 4.3 shows mean forefoot linear Fz results were similar for all shoe conditions (P = .151).

Inward Forefoot (Back-foot During the Follow-through)

Shoe	Fz (N)	SD	SE	Tz (N.m)	SD	SE	Limiting Friction
Yellow	346.11	5.22	1.85	10.75	2.64	0.94	0.031
Blue	348.58	4.68	1.65	10.70	1.85	0.65	0.031
Green	348.41	6.43	2.27	14.30	1.63	0.58	0.041
Red	344.69	13.09	4.63	10.97	1.74	0.61	0.032
Black	345.61	3.92	1.39	5.79	1.81	0.64	0.017

Table 4.4. Mean Inward Forefoot Results.

(Note: values are at the point slipping occurred within the shoe condition).

Table 4.4 shows mean Fz inward rotation results which were similar for all shoe conditions (P =.819).

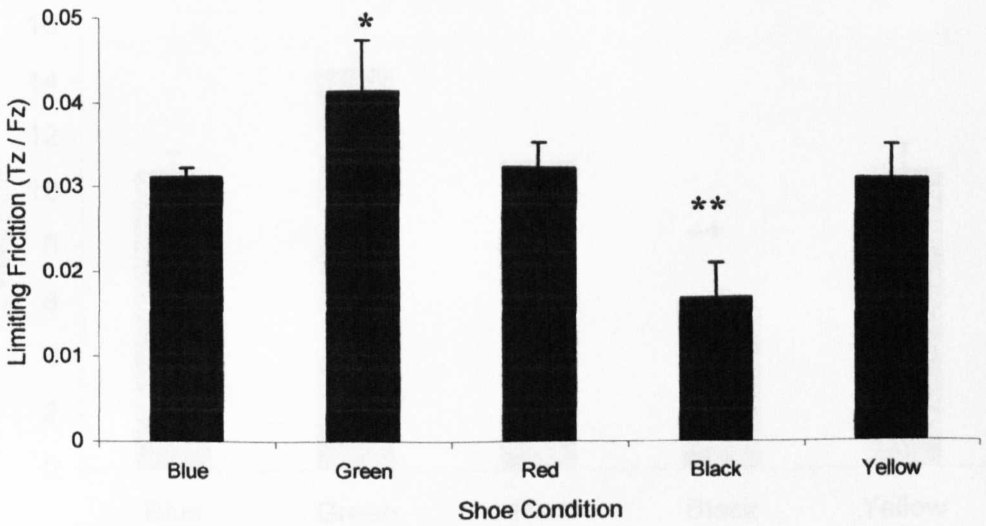


Figure 4.13. Forefoot Limiting Friction Anti-Clockwise Rotation. (** Denotes significant differences)

Forefoot Inward Rotation Limiting Friction: analysis identified the following shoes to be significantly different ($F(4,28) = 20.13$, $P = <.05$) to each other; The flat-soled Black shoe was found to produce significantly lower inward limiting friction when compared to all other shoe conditions supporting H_{2a}, H_{2b}, H_{3a} and H_{3b}, rejecting H_{02} and H_{03}. The Green traditional spiked shoe was identified to produce significantly higher forefoot inward rotation limiting friction compared to all other shoe conditions supporting H_{2a}, H_{2c}, H_{3a} and H_{3c} rejecting H_{02} and H_{3c}.

Forefoot Inward Rotation Tz Maximum: identified the following shoes to be significantly different ($F(4,28) = 20.61$, $P = <.05$) to each other. The flat-soled Black shoe condition produced significantly lower inward Tz values compared to all other shoe conditions supporting H_{2a} and H_{2b}. The traditional metal spiked Green shoe condition produced significantly greater inward Tz traction when compared to all other shoe conditions supporting H_{2a}, H_{2c} and H_{3c}.

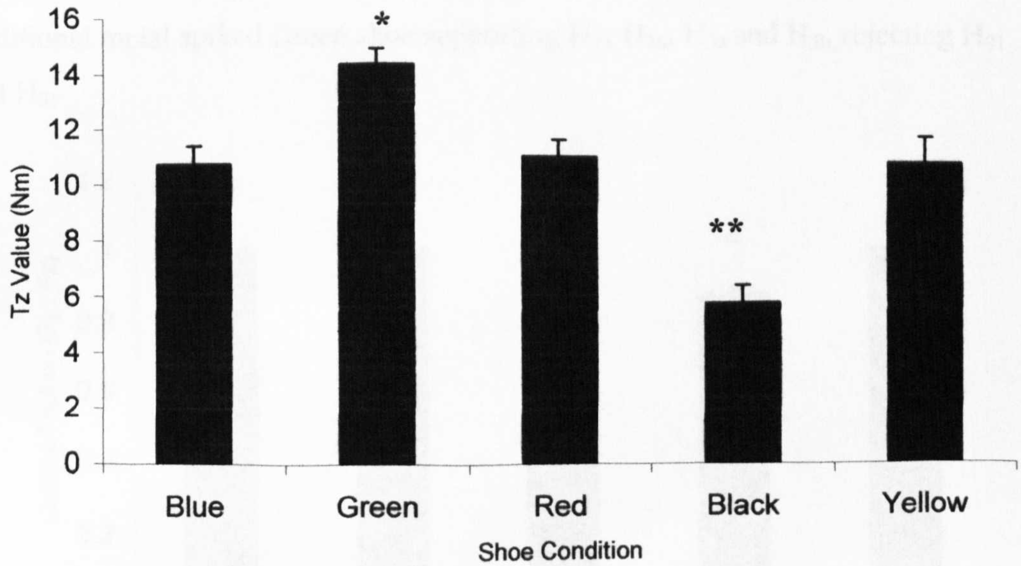


Figure 4.14. Forefoot Tz Maximum Inward Rotation.
(*Denotes significant differences)

Linear Whole-foot

Shoe	Fz (N)	SD	SE	Fy (N)	SD	SE	Limiting Friction
Yellow	351.71	39.35	13.91	356.68	3.66	1.29	1.01
Blue	356.54	28.91	10.22	354.90	3.91	1.38	1.00
Green	365.29	13.01	4.60	368.09	5.18	1.83	1.01
Red	350.35	8.46	2.99	356.65	6.66	2.35	1.02
Black	352.11	5.83	2.06	309.02	3.20	1.13	0.88

Table 4.5. Mean Linear Whole-foot Results
(Note: values are at the point slipping occurred within the shoe condition).

Table 4.5 shows mean Fz linear whole-foot results were similar for all shoes ($P = .754$).

*Linear Whole-foot Limiting Friction***:** identified the following shoes to be significantly different ($F(4,28) = 15.40$, $P = <.05$) to each other;
The Black flat-soled shoe produced significantly less linear whole foot limiting

friction when compared to the alternative spiked Yellow, Red, Blue and the traditional metal spiked Green shoe supporting H_{1a}, H_{1b}, H_{3a} and H_{3b}, rejecting H_{01} and H_{03}.

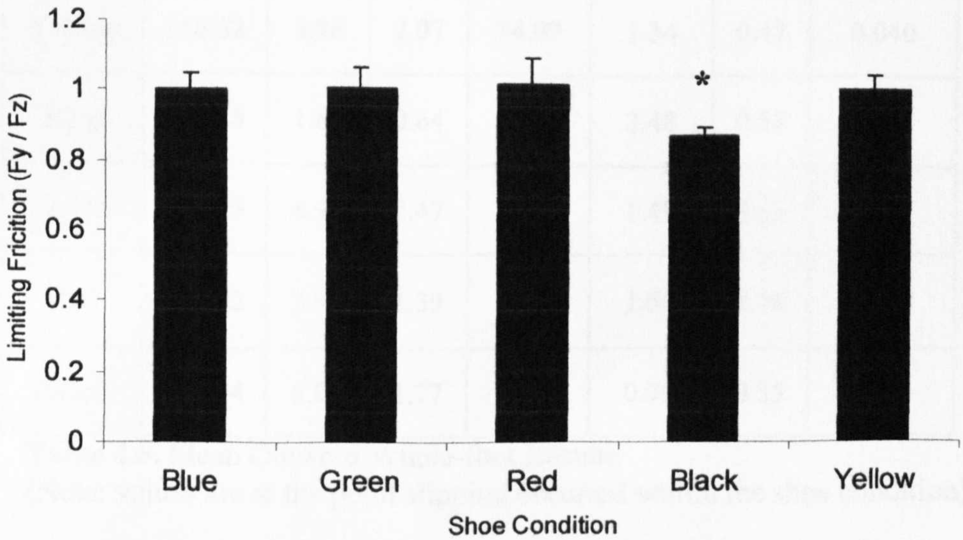


Figure 4.15. Linear Whole-foot Limiting Friction (* Denotes significant Difference)

Fy Maximum Linear Whole-foot; results identified the following shoes to be significantly different ($F(4,28) = 175$, $P = <.05$) to each other; The traditional metal spiked Green shoe condition produced significantly higher Fy forces when compared to all other shoe conditions supporting H_{1a} and H_{1c}. The flat-soled Black shoe condition was also identified to produce significantly less Fy maximum forces compared to all other shoe conditions supporting H_{1b}.

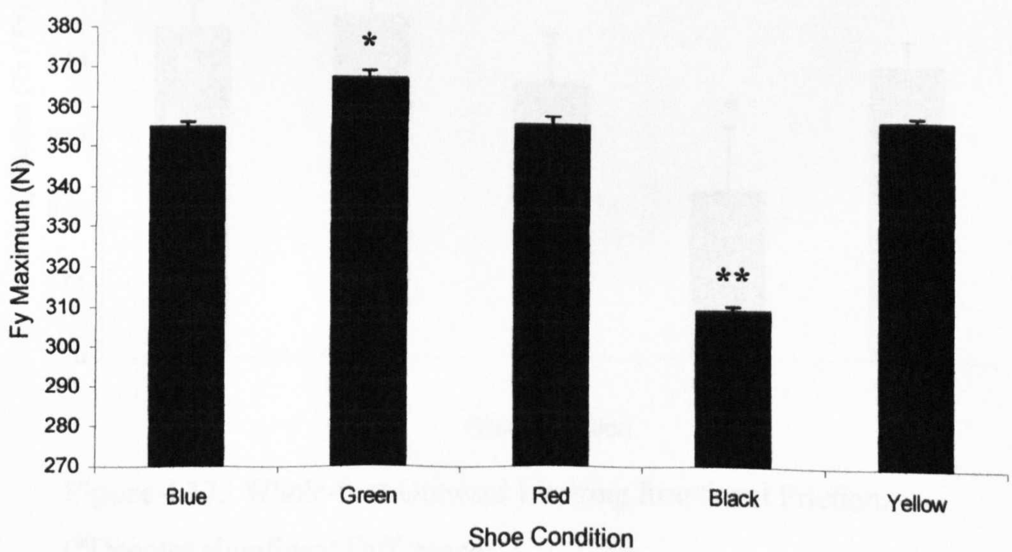


Figure 4.16. Fy Maximum Linear Whole-foot Limiting Friction.
(** Denotes Significant Difference)

Outward Whole-foot (Supporting Leg During the Back-swing and Follow-through)

Shoe	Fz (N)	SD	SE	Tz (N.m)	SD	SE	Limiting Friction
Yellow	350.52	5.86	2.07	14.09	1.34	0.47	0.040
Blue	351.38	1.81	0.64	15.69	2.48	0.88	0.045
Green	356.75	6.99	2.47	16.67	1.49	0.53	0.047
Red	353.82	3.95	1.39	13.47	1.65	0.58	0.038
Black	351.94	5.01	1.77	7.97	0.99	0.35	0.023

Table 4.6. Mean Outward Whole-foot Results
(Note: values are at the point slipping occurred within the shoe condition).

Table 4.6 shows mean whole-foot Fz outward results which were similar for all shoe conditions (P =.102).

Whole-foot Outward Rotation Limiting Friction results identified the following shoes to be significantly different ($F(4,28) = 29.87$, $P = <.05$) to each other; The flat-soled Black shoe was found to produce significantly less outward rotational limiting friction to all other shoe conditions supporting H_{2a} and H_{2b}.

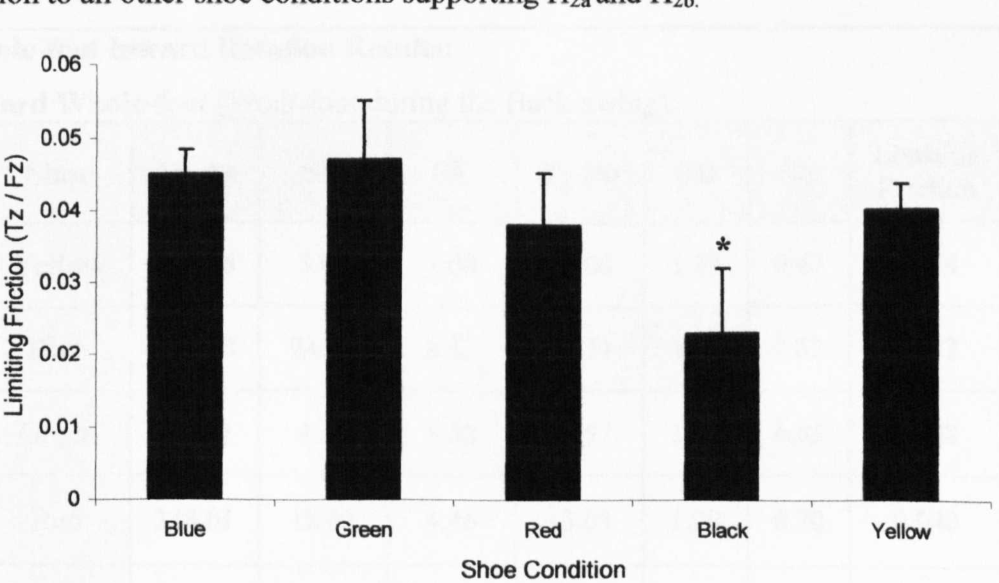


Figure 4.17. Whole-foot Outward Limiting Rotational Friction.
(*Denotes significant Difference)

Whole-foot Outward Rotation Tz Maximum results identified the following shoes to be significantly different ($F(4,28) = 107$, $P = <.05$) to each other; The flat-soled Black shoe condition was identified with significantly less Tz rotation to all other shoe conditions supporting H_{2a} and H_{2b}. The traditional Green shoe condition produced significantly greater Tz value when compared to the alternative Red shoe condition supporting H_{2a} and H_{2c}.

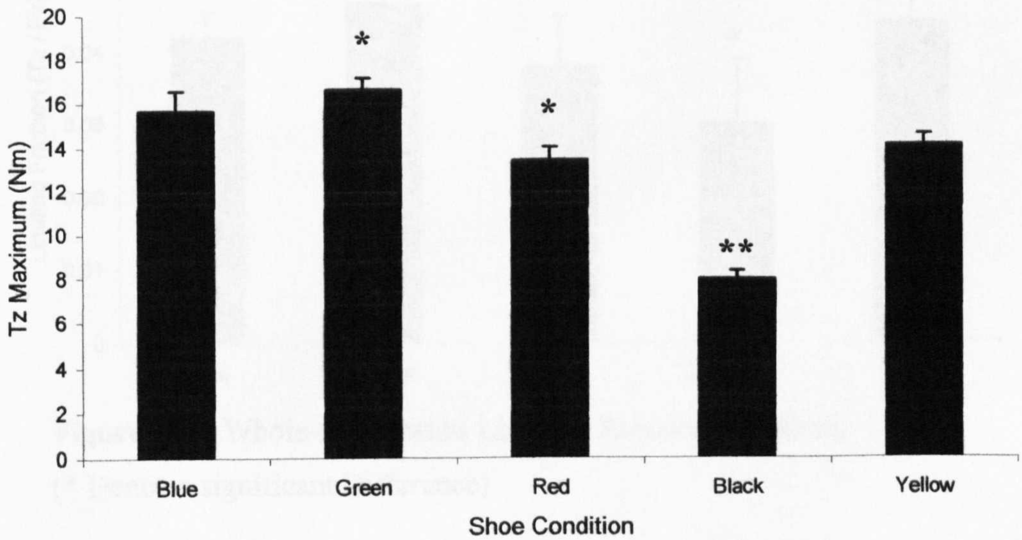


Figure 4.18. Whole-foot Tz Maximum Outward Rotation.
(* Denotes where the significance lies)

Whole-foot Inward Rotation Results:

Inward Whole-foot (Front-foot during the Back-swing)

Shoe	Fz (N)	SD	SE	Fy (N)	SD	SE	Limiting Friction
Yellow	344.86	3.06	1.08	15.06	1.33	0.47	0.044
Blue	348.58	24.09	8.52	14.74	1.74	0.62	0.042
Green	344.21	4.30	1.52	16.57	1.83	0.65	0.048
Red	348.01	12.62	4.46	13.05	1.99	0.70	0.040
Black	341.27	8.92	3.15	10.29	1.39	0.49	0.030

Table 4.7. Mean Inward Whole-foot Results
(Note: values are at the point slipping occurred within the shoe condition).

Whole-foot Inward Rotation Limiting Friction results identified the following shoes to be significantly different ($F(4,28) = 38.16$, $P = <.05$) to each other; The flat-soled Black shoe was found to produce significantly less outward rotational limiting friction to all other shoe conditions supporting H_{2a}, H_{2c}, H_{3a} and H_{3b}.

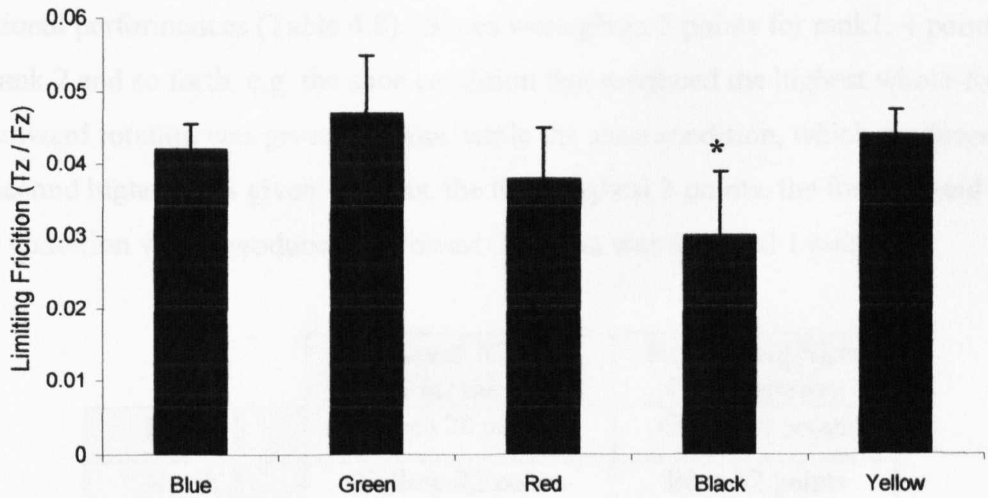


Figure 4.19. Whole-foot Inward Limiting Rotational Friction. (* Denotes significant Difference)

Whole-foot Inward Rotation Tz Maximum results identified the following shoes to be significantly different ($F(4,28) = 80.99$, $P = <.05$) to each other; The flat-soled Black shoe condition was identified as producing significantly less Tz rotation to all other shoe conditions supporting H_{2a} and H_{2b}.

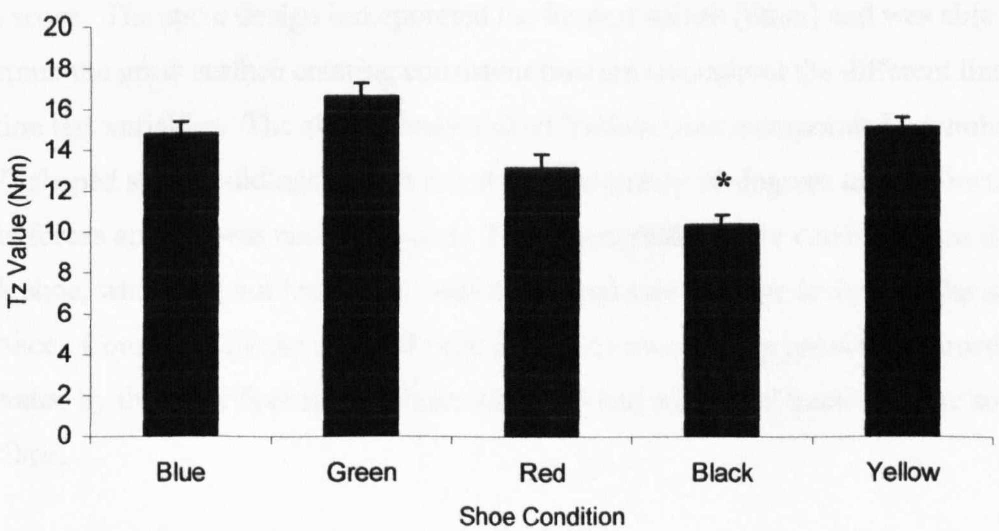


Figure 4.20. Whole-foot Inward Maximum Tz (* Denotes significant Difference).

Table 4.7 shows mean whole-foot inward rotation results, no significant differences were identified between shoe conditions within maximum Fy (P =.810).

Shoe Performance Ratings:

All shoe conditions were ranked against each other for their overall linear and rotational performances (Table 4.8). Shoes were given 5 points for rank1, 4 points for rank 2 and so forth. e.g. the shoe condition that produced the highest whole-foot Tz outward rotation was given 5 points, while the shoe condition, which produced the second highest was given 4 points, the third highest 3 points, the fourth 2 and the shoe condition which produced the lowest Tz value was awarded 1 point.

	Linear Shoe Performance	**Rotational Shoe Performance**
Rank 1	Green 28 points	Green 38 points
Rank 2	Yellow 22 points	Blue 32 points
Rank 3	Blue 17 points + Red 17 points	Yellow 28 points
Rank 4		Red 27 points
Rank 5	Black 8 points	Black 11 points

Table 4.8. Overall Linear and Rotational Shoe Performance Ratings.

Linear Shoe Performance Ratings:

The table identifies the Green traditional metal spiked shoe to produce the highest rank score. The spike design incorporated the longest spikes (8mm) and was able to penetrate the grass surface creating consistent traction throughout the different linear traction test variables. The alternatively spiked Yellow shoe incorporated a number of 'Z' shaped sole mouldings, which ran at approximately 90 degrees to the direction of the forces applied was ranked second. The lowest ranked shoe condition was the black shoe, which did not incorporate any additional sole traction designs on the sole interface. Consequently the shoe sole was unable to consistently provide the traction generated by the other four spiked shoes which all had additional traction at the sole interface.

Rotational Shoe Performance Ratings:

The Green shoe condition consistently produced the most rotational traction. As previously stated the shoe incorporated the longest spikes, which penetrated the grass surface, creating the rotational traction. The highest placed alternative spiked shoe was the Blue shoe. The Yellow and Red shoes produced comparable performance, while the flat-soled Black shoe was unable to generate consistent traction during the shoe's rotation.

The results indicate significant differences between shoe conditions were identified within linear, rotational and limiting friction ground action forces, supporting H_{1a}, H_{1b}, H_{1c}, H_{2a}, H_{2b}, H_{2c}, H_{3a}, H_{3b} and H_{3c}, rejecting H_{01}, H_{02} and H_{03}.

4.7: Discussion

Using a traction testing system, the study simulated comparable movements and forces that are created at the shoe sole interface during a golf swing. Unlike past research the present study also identified forces occurring upon the whole-foot (sole flat on the surface) as well as upon the forefoot of the sole as identified within past studies. During the golf swing the front and back feet / shoes are placed flat on the ground throughout the backswing and downswing until ball contact, as a result traction tests were performed on the whole-foot section of the shoe. Following ball impact the front-foot remains flat on the ground creating a fixed point for the golfer to rotate around, while the rear foot rotates onto the medial forefoot region of the shoe sole. Rotary forces and movements that are produced by the forefoot and whole-foot during the golf swing were also measured. Due to the novel whole-foot and rotational testing procedures it was not possible to compare some findings with any past studies.

Linear Forefoot Friction Test Findings:

The Black flat-sole shoe condition produced significantly lower linear coefficient of friction and forefoot Fy maximum forces when compared to all other shoe conditions. The results identify that for stable and supportive traction the shoe sole must incorporate some form of sole interface additional traction to enhance the Fy and limiting traction coefficients forces required to produce the rotational body movements caused by the feet 'coupling'. The limiting friction coefficient results support Slavin and Williams (1995) research, which also identified a flat-soled shoe to offer significantly lower coefficients of friction when compared to spiked shoes on a grass surface. Bonstincl *et al.,* (1975) lend further support from testing different sports shoes on grass surfaces and concluding that non-spiked shoes consistently developed less traction when compared to spiked shoes.

The results further support Williams and Sih's (1998) research, which identified a flat-soled shoe to produce a traction coefficient of 0.39, significantly lower than shoes with additional traction. The 0.39 traction coefficients measured for the flat-soled shoe is lower than the 0.66 value identified within the present study. It is probable that the higher coefficient of friction obtained from the current research was due to differences in grass conditions and testing procedures. Williams and Sih's (1998) research was conducted on an "artificial surface"; as a result the traction coefficients are likely to be different (between the different natural grass and artificial surfaces). The artificial surface would not compress or deform when vertical or horizontal forces were applied. As a result a flat-soled shoe would slip at lower forces (resulting in lower limiting friction coefficients). The natural grassed surface allows the shoe sole to partially imbed itself into the grass resulting in higher coefficients.

The traditional metal spiked Green shoe condition produced significantly higher forefoot linear Fy traction compared to all other shoes. This finding supports Slavin and Williams (1995) study that identified alternative spiked shoes to produce less traction when compared to traditional metal spiked shoes. Williams and Sih (1998) also identified that traditional spiked shoes produced the highest traction coefficients. They reported a limiting friction coefficient of 1.38 for the traditional metal spiked shoe in comparison to 0.97 identified within the present study. Williams and Sih (1998) study identified a traction coefficient of 0.96 for the alternative spiked golf shoes while the present study obtained slightly lower values of 0.91 (Yellow), 0.91 (Red), and 0.92 (Blue). It is probable that the differences in values of traction coefficient are due to differences between the grass and artificial surfaces. The higher value identified by Williams and Sih, is a result of the 'artificial surface' having limited 'give' as the spikes are able to penetrate the surface without tearing grass shoots or top soil as found on a natural grass surface.
From the five shoe sole conditions tested, the traditional metal spiked shoe would allow the most stable base for the foot coupling during the swing process. In contrast the limited limiting friction and Fy characteristics provided by the Black shoe would produce inadequate traction during the 'coupling' stage of the swing process resulting in limited control of the swing. At extremes the limited shoe linear traction could induce slipping when the applied forces exceed the tractional forces provided by the shoe conditions.

Whole-Foot Linear Friction Findings:

It is not possible to compare the present results with past studies as they all previously focused on forefoot-loaded trials. Whole-foot results give an understanding of the frictional properties of the shoes when the shoes are in full contact with the grass surface. This occurs within the left shoe throughout a right-handed golf-swing and in the right shoe during the backswing.

Maximum Fy and linear limiting friction coefficient tests showed that the Black flat-soled shoe had significantly lower linear limiting friction and Fy maximum values in comparison to all other shoes. The results further highlight the need for additional traction within the linear movement during the swing as previously identified in the forefoot condition. It is concluded that the flat-soled Black shoe sole was not appropriate for providing linear whole-foot traction and would limit a golfer's swing performance.

The traditional metal spiked sole incorporated seven 8mm metal spikes, which penetrated the grass surface creating significantly higher Fy maximum linear whole foot results in comparison to all other shoes.

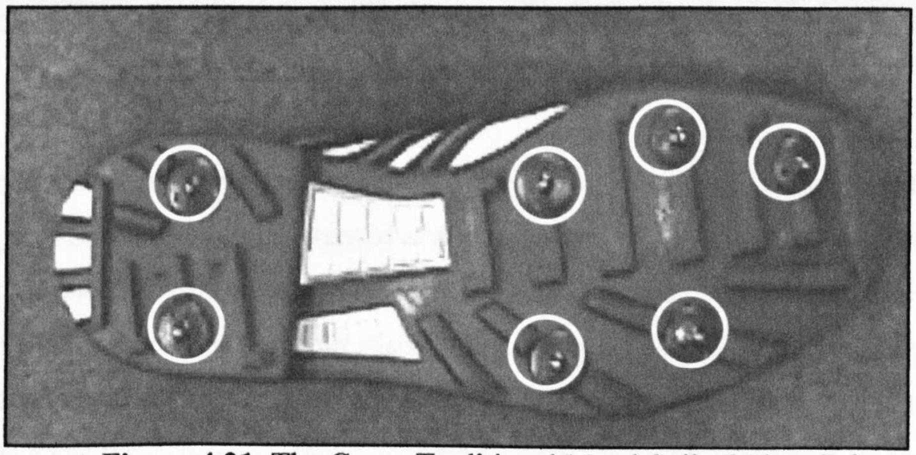


Figure 4.21. The Green Traditional Metal Spiked Shoe Sole.

The alternative spiked shoes incorporated spikes with a larger surface area but these were not as long as the traditional metal 8mm spikes. The alternative shoes had more sole mouldings and protrusions on the sole. The results suggest the current alternative spiked shoe sole designs are unable to produce comparable linear whole-foot traction to the traditional spiked design.

The Black shoe was ranked fifth overall in the linear shoe performances ratings highlighting the limited frictional properties associated with the shoe making it unsuitable for golfing performance. The Traditional metal spiked shoe was ranked first with high friction properties and thus supporting Slavin and Williams (1995) earlier work on artificial surfaces.

The highest linear friction produced by an alternative spiked shoe was identified within the Yellow shoe as shown in figure 4.22.

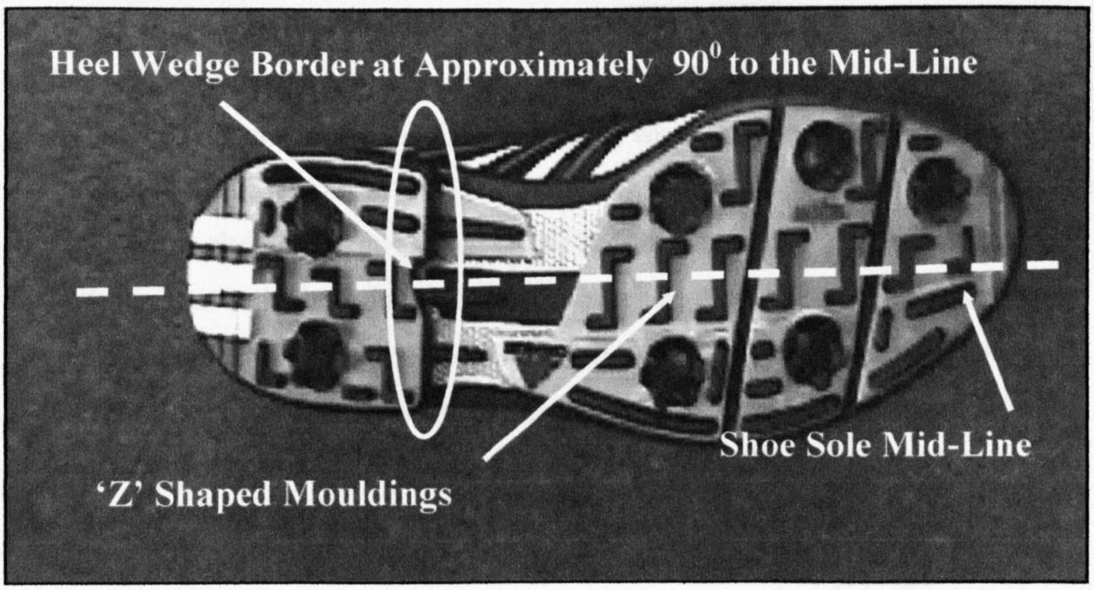


Figure 4.22. The Yellow Shoe Sole Design.

The Yellow shoe incorporated the Adidas 'Z-Traction Tour' sole, which integrated twelve 'Z' shaped mouldings situated at approximately 90^0 to the shoes mid-line. The mouldings and heel wedge position situated at approximately 90^0 produce traction in the anterior or posterior direction of the mid line resulting in the highest alternatively spiked shoe linear traction results. The Yellow shoe sole design may offer the basis for a shoe sole that can compete with the traditional metal spiked shoes frictional properties within the linear plane.

Forefoot Rotation Findings:

The present study replicated the specific movements and forces acting upon the shoe using a traction testing system. During a right-handed golf swing the right (back) shoe is transferred onto the forefoot during the downswing and follow-through, while the left (front) shoe maintains a flat whole-foot contact with the ground surface through the whole swing. As a result the present study did not test forefoot outward rotation, as this does not occur during an actual golf swing.

Inward Rotational Traction Findings:

Inward rotational forces occur at the front-foot during the backswing. The shoe is required help balance the golfer as the club and golfer rotate clockwise around the back-foot and leg. Inward rotational forces are identified within the back-foot during the downswing when the whole foot is placed on the ground surface allowing the golfers weight to transfer onto the front-foot (left). Forefoot inward rotation of the back-foot then occurs during the follow-through when the shoe rotates onto the medial forefoot edge (big toe). This allows the golfer to decelerate the anticlockwise rotations of the club and body around the front-foot / leg following ball impact.
As both forefoot and whole-foot inward forces are applied to the golfer's shoes during a dynamic swing the same principle was applied within the present testing.
If the right golf shoe provides excessive forefoot friction it will impede the natural rotation during the swing. As a consequence shoes that offer lower forefoot rotational traction at this stage would facilitate the swing in a more natural manner.

Within the forefoot inward results the flat-soled Black shoe condition produced significantly lower limiting friction coefficients inward Tz values compared to all other shoe conditions. Unlike the previous linear forefoot findings, the limited traction provided by the Black flat-soled shoe would enhance the golfing movement, facilitating back-foot forefoot inward rotation, essential for the natural rotational movement around the front-foot. Although the design feature will not enhance the golf shot, as the movement occurs after ball impact the Black shoe incorporates an important shoe characteristic to facilitate a smooth follow through.

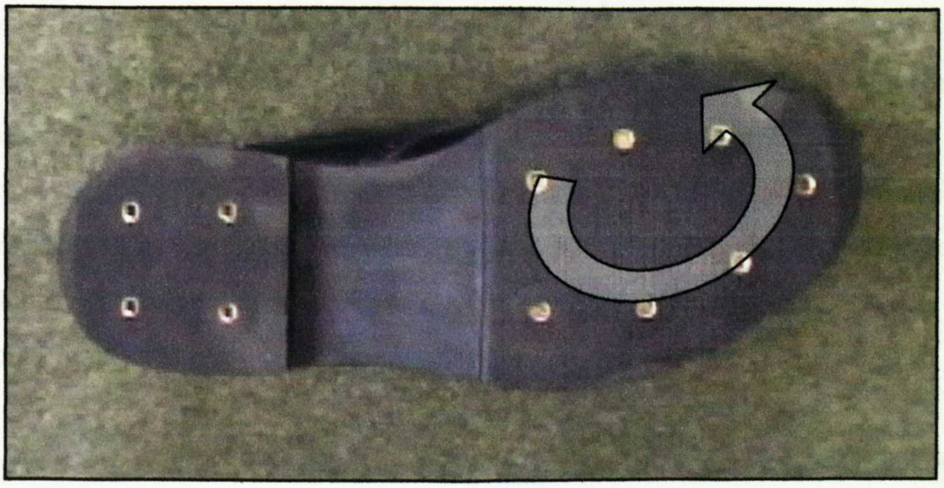


Figure 4.23. Black Flat-Soled Shoe.

The traditional spiked Green shoe was identified to produce significantly higher forefoot inward rotation-limiting friction and Tz forces when compared to all other shoe conditions. The shoe design would inhibit the natural inward rotation of the rear foot, causing restriction of the rear foot, hip and ultimately the upper body's movement during the later stages of the downswing and follow-through.

During a normal golf swing no inward forefoot rotation will occur at the front-foot (right-handed swing). The front-foot / shoe will be subjected to the highest rotational forces occurring during the swing process when the golfer transfers their bodyweight from the back-foot to the front-foot. At ball impact the club head and golfers body will be rotating at its maximum velocity, then rapidly decelerate around the fixed front leg / foot. Due to the excessive rotational forces the whole of the front-foot remains flat on the ground. It is important that the forefoot has appropriate traction so the front-foot does not move during these critical stages of the swing. Any unexpected inward slipping within the front-foot would be detrimental to the shot performance and possibly risk injury highlighting the flat-soled shoes traction limitations. The results identified the Black shoe produced significantly less rotational limiting friction and Tz maximum forces when compared to all other shoe conditions. The traditional metal spiked Green shoe produced significantly higher Tz forces, further identifying the frictional properties of the longer metal spikes.

Outward Rotational Traction Findings:

During the back-swing clockwise rotation of the body and resultant outward forces the golf shoes are required to maintain a stable position enabling the golfer to develop a 'coiled position' ready for a fast downswing. Although the rotational forces are much lower than in the front-foot it is important that this stable footing is maintained within the rear foot (right foot for a right handed swing) as this acts as a rotational point creating a coiled position.

During the downswing and follow-through large outward rotations are placed upon the front-foot. It is important that the front-foot (left foot on a right handed golfer) maintains a stable position on the whole of the shoe sole while the golfers body weight is transferred and rotated around it. Inadequate sole traction will cause an inward lateral slip, resulting in limited club control and possible ankle and knee injury. During the golf swing there is no forefoot outward rotation as the outward movement is predominantly produced the whole-foot of both front and back feet. Consequently no outward forefoot traction tests were performed.

The results further support those identified within the previous linear and rotational results with the Black flat-soled shoe produced significantly lower Tz maximum and limiting friction coefficient to all other shoe conditions. Throughout the backswing the back-foot needs to remain fixed to allow a 'coiling' around the back-foot / leg. With limited traction this would not be possible. The results emphasis the possibility of erroneous shot performance and increased knee and ankle injury risks when using a flat-soled shoe at this stage of the swing process.

The maximum Tz outward rotation results identified the Green traditional metal spiked shoe to produce significantly higher Tz forces when compared to the Red alternative shoe condition. Although not significantly different the Red shoe produced the lowest forces when compared to the other alternative spiked shoes.

Figure 4.24. Red Alternative Shoe Sole Design with Outward Rotational Forces Highlighted

The Red sole incorporated five raised straight mouldings on the medial forefoot and three heel mouldings, which were positioned running in the same direction as the outward forces applied (Figure 4.24). It is possible that the position and angle of these mouldings increased the rotational movement limiting sole traction when it was applied to the shoes forefoot.

In agreement with linear frictional results the Black shoe was ranked fifth overall in the rotational shoe performances ratings further highlighting the reduced frictional properties associated with the shoe. As identified within the linear friction variables the traditional metal spiked Green shoe produced also provided the highest friction further supporting Slavin and Williams (1995).

From the alternatively spiked shoes the Blue shoe provided the highest total rotational performance rating. The shoes sole mouldings were shaped and situated in positions that ran against the direction of the rotational applied forces. The Blue shoe sole only incorporated four forefoot spikes in comparison to five on all the other alternative spiked soles. This did not however limit the rotational traction of the shoe.

Figure 4.25. Blue Shoe Sole Design.

The heel wedge was also moulded into the shoes forefoot section. This resulted in a larger surface area of the sole and forefoot making contact with the grass surface, increasing the sole's traction.

Limitations within the Current Testing Modality:

Limitations within the repeatability of the testing using real grass surfaces occurred. Differences in the moisture content and altered turf conditions caused a number of possible reliability problems. Presented data from testing was therefore carried out on all the shoe conditions using the same batch of turf on the same day to maintain consistency between turf sods. Turf was only used within the study when a moisture probe categorised it at level 2, therefore maintaining comparable turf conditions.

It has been stated that to gain an accurate understanding of the functions and performance of sports shoes, they must be tested within a real life environment with the same forces applied to them at the appropriate velocities (Slavin and Williams, 1995). Further Nigg (1989) stated that tests for the assessment of translational and / or rotational traction characteristics should be performed using the actual forces between athlete and surface. Tests performed with smaller forces may lead to erroneous conclusions. The low rate of application of force in the present tests may therefore limit the validity when applying the results to actual golf performance situations.

4.8: CONCLUSION

The mechanical traction tests for the assessment of frictional characteristics of the shoes provided information on the shoe-surface interaction. The results highlight the flat-soled shoes inability to produce equivalent traction to that produced by the spiked shoes, further identifying the need for spikes and sole protrusions to increase frictional forces. The traditional spiked shoe performed consistently well throughout the testing, highlighting the longer single 8 mm spikes ability to limit the probability of the shoe slipping forward in the linear or rotational directions when compared to alternative and flat-soled shoes. Alternative spiked shoes consistently produced greater traction values when compared to the flat-soled shoe, but were unable to provide comparable traction to the traditional spiked shoe. The results identify concerns regarding the alternative spike and sole designs, as the functional traction currently provided do not offer the traction provided by traditional metal spiked shoe.

The findings highlight difficulties within the shoe sole interface design as during the downswing the back-foot needs to rotate with minimal rotational friction but high linear friction, while simultaneously the front-foot is required to offer high linear and rotational frictional properties within the front-foot during the same stage. The current findings identify the need for differing shoe sole interfaces for the front and back shoe sole as identified by Carlsoo, (1967), Williams and Cavanagh, (1983), Koenig and Tamres (1992), and Thomas and Pietrocarlo, (1996). The realisation of different sole beds would need to be met without compromising the natural walking gait of the golfer.

The mechanical results enable an understanding of how the shoe sole interfaces perform when constant forces are applied in a controlled manor. Although linear and rotational forces were applied to the forefoot and whole foot, it has been questioned if this information can be directly related to the dynamic forces applied by a golfer during a golf swing. Slavin and Williams (1995) stated that 'to gain an accurate understanding of the functions and performance of sports shoes, they must be tested within a real life environment with the same forces applied to them at the appropriate velocities'.

As is not possible to exactly replicate the amount and directions of forces applied to the shoe during the swing, dynamic analysis of the shoe sole interface is required. Thomas and Pietrocarlo, (1996) identify that the motion of the various body parts trigger reactive forces from the shoe-ground interface yielding useful information of the foot biomechanics of the swing. Through dynamic force analysis on natural grass surface an understanding of the shoe sole interface functional properties during the golf swing will be gained.

CHAPTER 5: PERFORMANCE CHARACTERISTICS OF MODERN GOLF SHOE SOLE AND SPIKE DESIGNS

5.1: INTRODUCTION

An understanding of the tractional performance of different shoe sole interfaces was gained within chapter 4 through mechanical testing. Such mechanical testing of shoe sole traction may not give an accurate understanding of the shoes' performance during an actual golf swing. Only during the actual golf swing process can accurate dynamic forces be created by the golfer and thus subjected to the golf shoe.

Few studies have compared alternative spike designs and the forces exerted onto the sole bed during the actual golf swing, despite belief in the importance of dynamic forces transferred during the golf swing (Kawashima *et al.*, 1998). Relatively little dynamic research has been reported in the years since this observation was made. As a result comparative research into alternative, traditional and flat-soled spiked shoes functional performance during the golf swing has not been identified.

5.2: LITERATURE REVIEW

As previously identified very little was known about the importance of the golf shoe and foot biomechanics until the pioneering study by Williams and Cavanagh (1983). Williams and Cavanagh (1983) study provided an understanding of the forces and torques produced at the shoe sole interface of a traditional spiked golf shoe. The researchers suggested shoe sole modifications, which were different between the left and right shoes. They identified limited differences in the forces produced at the feet between different golfing abilities. However, although this study was informative it did not replicate a natural golfing situation / environment due to the laboratory setting and the 'Astroturf' covered force plate, resulting in unrealistic measures. During the swing process the feet work as a couple, generating linear and rotation forces. Another limitation of Williams and Cavanagh's study was that the ground reaction forces were only measured on one foot during each shot, alternating the monitored foot after each swing. Unfortunately it is not appropriate to presume that the forces produced by the front-foot in one swing will correspond to the forces generated within the back-foot during the next swing. Only through synchronising two force platforms can accurate force information be gained from both front and back feet.

Barrentine *et al.*, (1994) studied golfers in a similar indoor environment but with two force platforms covered with artificial grass to measure ground reaction forces. However, even with such differences in testing modalities the findings of both these latter studies were similar.

The studies of Williams and Cavanagh (1983) and Barrentine *et al.*, (1994) both identified that through the back swing, most of the golfer's weight shifted onto the rear foot with the foot applying torque in the clockwise direction (as viewed from above). Barrentine *et al.*, (1994) identified that "Because the spikes on the rear shoe locked into the ground, the reaction of this torque was to cause the golfer 's body to rotate in the counter-clockwise direction". At the start of the downswing, "The rear foot applied a maximum force in the lateral direction". Barrentine *et al.*, (1994) further stated, "Both feet then exerted a maximum force in the anterior-posterior direction. The rear foot pushed in the anterior direction while the front-foot pushed in the posterior direction. This created a clockwise force couple that occurred after the top of the back swing. Because the spikes were locked into the ground, the reaction force couple caused the golfers body to rotate in a counter-clockwise direction."

Barrentine *et al.*, (1994) identified that prior to and during ball contact "The front-foot applied a maximum shear force in the lateral direction and a maximum force in the vertical direction. The lateral shear force exerted by the front-foot helped stabilise the golfer and enabled the counter-clockwise velocities to be maximised. At this point, the golfer exerted a vertical force, which was greater than total (mean) bodyweight".

Williams and Cavanagh (1983) highlighted that the position and pattern of both shear and vertical forces were important factors influencing stability, force production and resistance to slippage during the swing. During a golf swing, the ratio of the shear to vertical force was identified to be typically highest during the downswing before ball contact (Williams and Cavanagh, 1983). If the shear forces exceed the resistance offered by the shoe for either foot at any point during the swing slipping would occur. Any irregular unexpected foot movement during the swing adversely affects performance (Slavin and Williams, 1995).

Following the introduction of alternative spikes research into the functional performance of the golf shoe during the golf swing has remained limited.

An investigation into alternative spike by Williams and Sih, (1998) examined changes in the force patterns exerted by the feet during actual golf shots, and if slipping was more likely to occur in alternative-spiked shoes. Using two force platforms covered in "Artificial turf" the study tested a flat-soled traditional and alternative spiked shoe. Willams and Sih (1998) identified no significant differences in the maximum and minimum ground reaction force measures during the golf swing when the alternative spike design shoe was compared to a regular spike shoe during golf shots. A limitation to Willams and Sih's (1998) study was that it was conducted on "Artificial turf" making it impossible to relate the shoe findings to the natural golf course surface, grass. No force or friction values for the flat-soled shoes were reported. At present there are few dynamic studies identifying the traction of flat-soled shoes during the golf swing as it is generally assumed that the traction would be severely reduced. This has limited the general understanding of the shoe ground relationship and its influence on golf shoe traction, as such 'base line' measures is not known.

Nikolai *et al.,* (1999) used psychological perception scales to gain a subjective view of golf shoes undergoing measurement to investigate shoe-surface force generation. They studied golfers' perception of the traction offered by traditional and alternative spikes during the golf swing. They used a rating scale of one to five (1=excellent traction, 2=very good, 3=good, 4 = fair, and 5 was considered poor traction). The results identified the traditional 8mm metal spike as receiving the highest percentage of 'Excellent' ratings while alternative spikes averaging only 'fair', possibly as a reflection of the golfers concerns about current alternative spikes. It was noted that some of the participants in the survey stated that it was difficult to rate the shoes for traction while ignoring the differences in comfort among the different pairs of shoes. This suggests that many golfers are unable to identify specific differences in the shoe's traction during the swing and just relate the shoe's performance simply to comfort.

Koenig and Tamres (1992) researched the function of the feet and shoes and how this was affected by golf handicap. Using three different clubs (driver, 3iron and 7iron) fourteen golfers were separated into three handicap groups (no details). The golfers' foot movements were measured in a laboratory using a force plate covered with 'Artificial turf' they identified that the forces generated by lower handicap players were significantly different to those of the higher handicap players (specific result values not stated). Koenig and Tamres (1992) suggested 'A person with a higher handicap should have a different shoe design than a better player.'

They further identified that the left and right shoes should be designed differently stating the placement of spikes were not suitable to aid the players swing and maintain stability, supporting the early findings of Williams and Cavanagh (1983) who also suggested that the shoes need to be different due to the nature of the foot movements during the swing process. At present asymmetrical traction designs have not been developed.

Within the few previously reported research studies to date (Williams and Cavanagh, 1983, Slavin and Williams, 1995 and Willams and Sih (1998), it has been questioned whether golf shoes actually offer golfers the support, traction and manoeuvrability needed for a smooth supportive golfing movement. The golf shoe is not only required to enable the performance of the highly demanding swinging motion but also to enable long distances to be walked comfortably during the golf round. However as Pforringer and Rosemeyer (1989) observed 'The shoes are not suitably designed for either activity. This is true not only for the shape of the shoe, but also for the type, number and location of the spikes.'

A major drawback of research to date into golf shoe design features has been the difficulty of relating laboratory-based findings to the actual game of golf. The artificial operating environment of the indoor golf station may affect the performance of the golfer, and the outcome of the shot is unknown. Williams and Sih, (1998) stated that further shoe assessments were needed using a natural grass surface, and conditions where slip was more likely to occur in order to further define any effect alternative-spike out-sole designs may have on golf swing dynamics.

To enhance the ecological validity of the research detailed within this chapter, the testing was performed outside on flat natural grass surfaces, with an open field of view. Golfers wore different out-sole golf shoe patterns and spike designs.

5.3: Aim

The aim of the present study was to investigate shoe-grass interface action forces and friction coefficients whilst wearing five types of golf shoes with different sole and spike patterns and designs. Three groups of golfing abilities used three different clubs were used to hit the same type of golf ball during a range of shots.

5.4. Hypotheses

5.4.1: Golf Shoe Design Hypotheses:

H_O: No differences in action forces will be identified between shoe conditions.

H_1: Spiked golf shoes will produce higher vertical action forces when compared to a flat-soled golf shoe.

H_2: Traditional metal spiked shoes will produce higher vertical action forces when compared to alternative spiked shoes

H_3: Spiked golf shoes will produce higher anterior-posterior action forces when compared to a flat-soled golf shoe.

H_4: Traditional metal spiked shoes will produce higher anterior-posterior action forces when compared to alternative spiked shoes

H_5: Spiked golf shoes will produce higher medial-lateral action forces when compared to a flat-soled golf shoe.

H_6: Traditional metal spiked shoes will produce higher medial-lateral anterior-posterior action forces when compared to alternative spiked shoes

H_7: Spiked golf shoes will produce higher rotational action forces when compared to a flat-soled golf shoe.

H_8: Traditional metal spiked shoes will produce higher rotational action forces when compared to alternative spiked shoes

5.4.2 Golfers Handicap Hypotheses:

H_O: No differences in action forces will be identified between handicap groups.

H_1: Different handicap groups will produce different action forces.

5.4.3 Golf Club Hypotheses:

H_O: No differences in action forces will be identified between golf clubs.

H_1: Different golf clubs will produce different action forces.

5.5: METHOD

Golf Equipment:

Clubs: Three different clubs were used by each subject in each shoe condition. The clubs were the subjects' own clubs, and thus those with which they were familiar. A driver, which incorporates the longest shaft with the largest head, and used for long powerful shots ranging on average between 180 – 260 meters. A 3iron, often the longest iron carried by players, and used for long shots from the fairway ranging between 170 – 220 yards. A 7iron, which is shorter in shaft length, and used for medium to short approach shots to the hole with a range of between 100 – 180 yards.

Balls: New Titleist DT white golf balls were used.

Tee Mat Surface: Golf shots were played off a rubber backed 'Astroturf' tee mat, which allowed tee pegs to be inserted if required.

Shoes: The five different types of golf shoes and their design factors are described within section 3.1.

Procedure:

Following ethical approval twenty-four right-handed male (age 27.1 ± 4.7) (mass Kg 75.3 ± 9.1) golfers volunteered for the study. Eight subjects had a low handicap (0-7), eight had a medium 8-14, and eight had a high handicap 15+. The subjects all played three times or more a month, with the highest handicap being 26 and the lowest 0. Each subject provided written informed consent and was reminded that withdrawal from the study at any time without prejudice was possible (Appendix C). Subjects were allocated as much time as they needed to warm up and become accustomed to each experimental shoe and club condition.

For the experimental testing subjects stood with a foot on each of the grass turf covered force platforms. The foot action forces of the right (back-foot) and left (front-foot) feet were measured simultaneously on two Kistler 9851B force platforms' (Kistler instruments Ltd). The force platforms were covered in a natural grass surface, similar to that found on a teeing off area on a golf course. Detailed force platform set-up is described within chapter 3.2.

The golf balls were hit off a tee mat to prevent surface wear. Golfers teed the ball up on rubber driving range tee pegs or hit directly off the Astroturf mat. When wearing each of the five shoes, five shots were played with each of the three clubs (i.e 15 shots were made in each shoe condition). Golfers were asked to play only straight shots and not to draw, or fade the ball. Shot outcomes were noted after each shot identifying if the shot was straight or miss-hit. Clarification of ball contact was requested from the golfer if a shot looked miss-hit. Club and shoe order was randomly assigned for each participant.

During data collection posterior lower leg and foot movements were captured using a JVC Compact VHS GR-FX 12EK video camera (50Hz sports mode 1/200 sec) to identify foot position for subsequent analysis. A separate 200 Hz High Speed Peak Systems Camera, (Peak Performance Technologies inc. Englewood, Colorado USA) was placed in front of the subject to capture the whole body movement. This allowed the whole body and club motions to be viewed.

A trigger from a small impact to the back of one force platform prior to the start of each golf swing enabled the video and force platform systems to be synchronised. The time of ball impact was determined by calculating the number of frames from a force plate signal to ball impact from the high-speed video footage to the nearest 0.005 second. The test environment can be seen in figure 5.1.

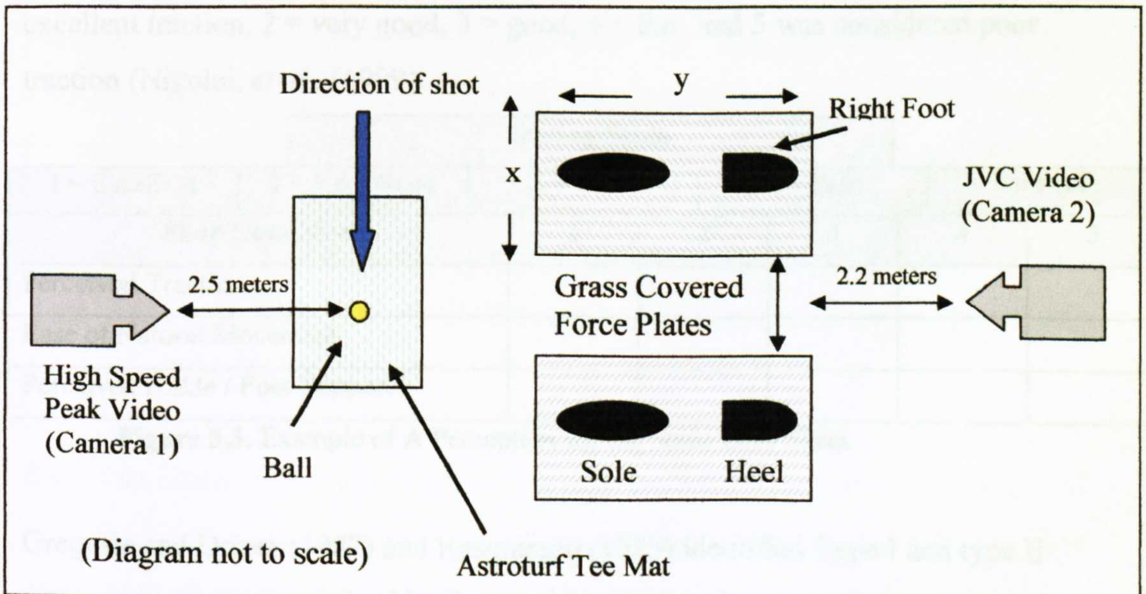


Figure 5.1. Test Environment for a Right Handed Golfer.

Foot action forces and moments were measured through the two force platforms as shown in figure 5.2. The clockwise rotation denotes a positive force moment while the clockwise rotation denotes a negative ground reaction force moment.

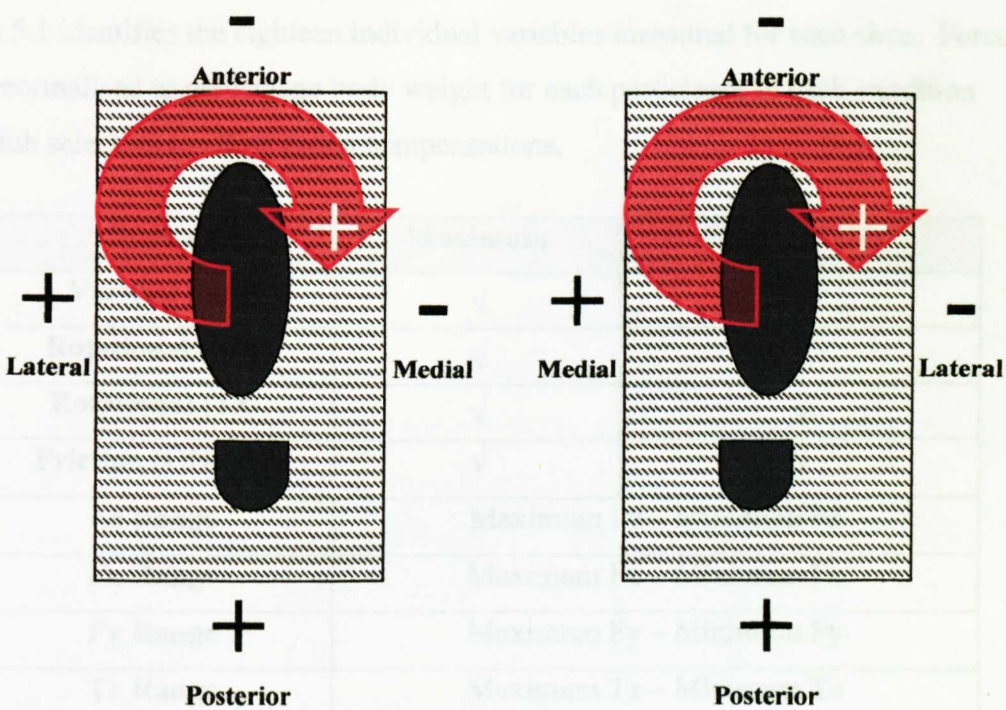


Figure 5.2. Platform Orientation Showing Foot Action Forces.

Each subject completed a questionnaire relating to their perceptions of each shoe in terms of perceived traction, ease of natural foot movement and ankle / foot support during the golf swing (Figure 5.3). A rating scale of 1 to 5 was used with 1 = excellent traction, 2 = very good, 3 = good, 4 = fair, and 5 was considered poor traction (Nikolai, *et al.,* (1999).

Rating Scale					
1 = Excellent	2 = Very Good	3 = Good		4 = Fair	5 = Poor
Shoe Condition		**1**	**2**	**3**	**4**	**5**
Perceived Traction						
Ease of Natural Movement						
Perceived Ankle / Foot Support						

Figure 5.3. Example of A Perception Rating Scale Data Sheet

Gregorie and Driver (1987) and Rasmussen (1989) identified Type I and type II errors were not compromised by the use of ordinal-scale data and that parametric tests showed power superiority to non-parametric tests when performed on non-parametric data. Consequently mean perception scores were subjected to a one-way ANOVA with repeated measures (shoe) within the present study.

Table 5.1 identifies the eighteen individual variables measured for each shoe. Forces were normalised to percentage body weight for each participant in each condition and club selection to allow group compensations.

Forces	Maximum	Time of Max
Vertical (Fz)	√	√
Rotational (Mz)	√	√
Rotational (Tz)	√	√
Friction (COFxy)	√	√
Fz Range	Maximum Fz – Minimum Fz	
Fx Range	Maximum Fx – Minimum Fx	
Fy Range	Maximum Fy – Minimum Fy	
Tz Range	Maximum Tz – Minimum Tz	
Mz Range	Maximum Mz – Minimum Mz	
Weight Transfer Time	Front-foot Fz max time – back-foot Fz max time	

Table 5.1. Variables tested within the study (√ tested, × not tested)

Mean and standard errors were calculated for all kinematic and force platform data. Sphericity was assessed using Mauchly's Test to identify if variance of differences between conditions were equal. If sphericity was not assumed, a Greenhouse-Geisser correction was used. Data was then analysed using two-way mixed design ANOVAs (handicap / shoe), (handicap / club) with repeated measures at a 5% significance level. Significant differences were detected by Post Hoc Tukey HSD tests set at a 5% level of significance.

Raw action force data can be seen in appendix D. Within the raw data a number of individual values are missing within some measured variables. The omitted values are a result of errors within the recorded data set during the testing process.

The key features of the force parameters are given below:

- Vertical peak force (Fz): The Fz value relates directly to the transmission of upward and downward forces through the musculo-skeletal system and is usually expressed in units of body weight (BW) (1.0 = 1.0 x the individual's body weight).
- Medial / Lateral force (Fx): The Fx value (BW) is a measure of forces acting between the medial and lateral sides of the foot identifying medial and lateral weight transfer during the swing.
- Anterior / Posterior force (Fy): The Fy (BW) Anterior / Posterior force is a measure in the golf swing activity associated with rotational body movements and will closely relate to the anterior / posterior traction properties of the shoe.
- Mz vertical moment rotational force (N.m): Mz is a force couple about the vertical 'Z' axis of the force-platform which results from shear forces between the foot and ground. Depending on the direction of the free moment, it acts to resist the tendency of the foot to either abduct (toe out) or adduct (toe in) with respect to the ground (Holden and Cavanagh, 1991).
- Tz rotational torque (N.m): The free moment about the centre of pressure.
- COFxy frictional force (BW): Co-efficient of friction on the horizontal x and y plane.
- Fz Range (N.m): Fz minimum – Fz Maximum = Fz range.
- Fx Range (N.m): Fx minimum – Fx Maximum = Fx range.
- Fy Range (N.m): Fy minimum – Fy Maximum = Fy range.
- Tz Range (N.m): Tz minimum – Tz Maximum = Tz range.
- Mz Range (N.m): Mz minimum – Mz Maximum = Mz range.
- Time of weight transfer (Sec): Normalised front-foot time of Fz maximum – Back-foot time of Fz maximum = Time of weight transfer.

5.6: Results

Shot Outcome Results:

The following results are based on total shots in all shoe conditions using all three clubs.

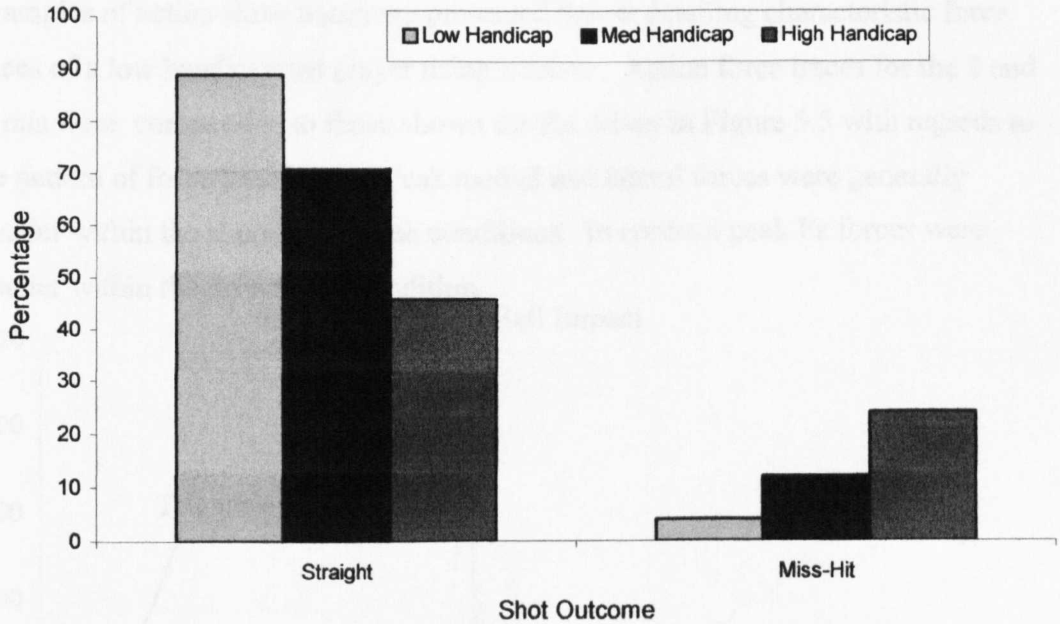


Figure 5.4. Shot Outcome Results Between Handicap Groups

The low handicap players hit 89% of their shot straight. The medium handicapped players maintained 71% of their shots straight, with 29% being miss-hit. The high handicapped players hit only 46% of their shots straight with 54% hitting miss-hits.

Golfers action forces were measured within each shot played. The following graphs and tables identify examples and results of the action forces measured during the swing process.

Action Force Results.

All raw action force result data can be seen in appendix D.

Low Handicap Golfer Example Action Force Traces.

5.6.1.1: Driver.

Examples of action force traces are presented below detailing characteristic force traces of a low handicapped player using a driver. Action force traces for the 3 and 7irons were comparable to those shown for the driver in Figure 5.5 with regards to the pattern of force production. Peak medial and lateral forces were generally smaller within the shorter iron club conditions. In contrast peak Fz forces were smaller within the driver club condition.

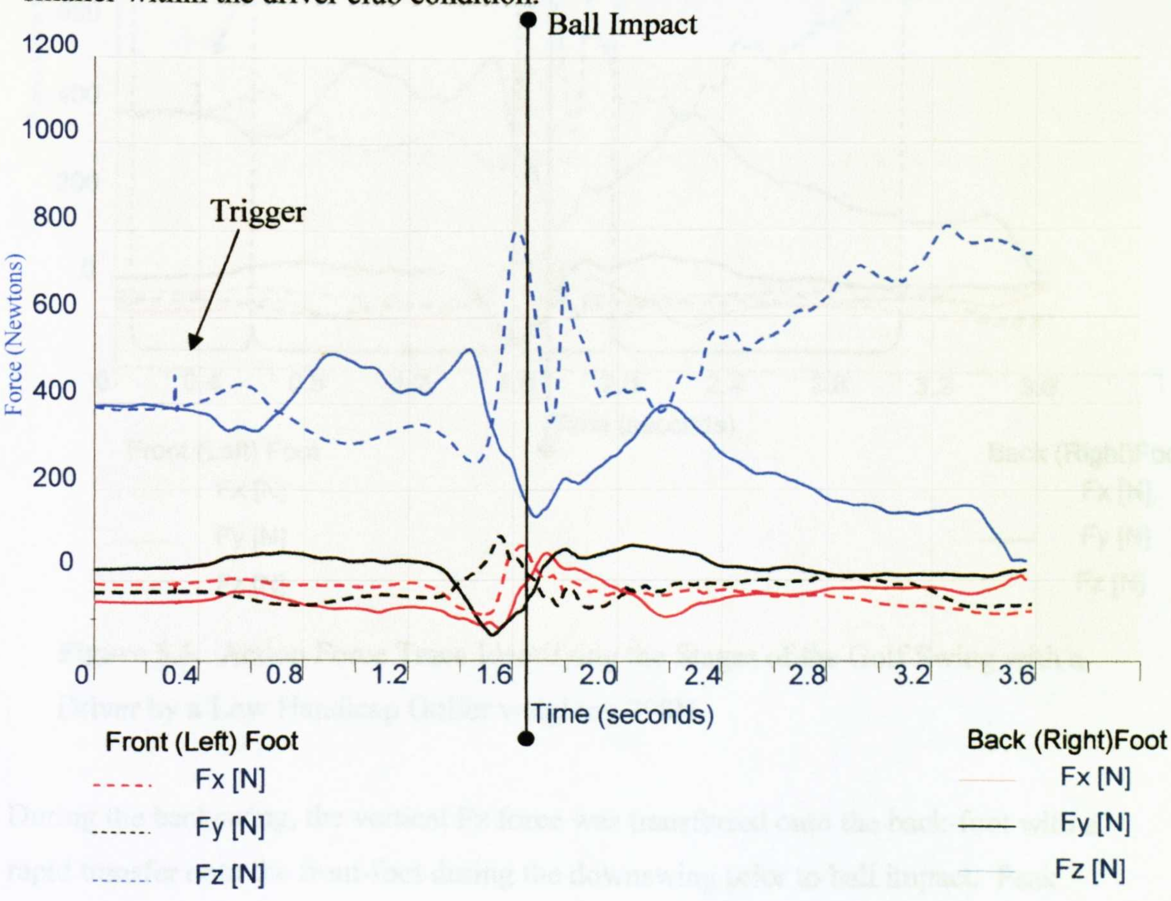


Figure 5.5. Action Forces During the Golf Swing by a Right-Handed Golfer when a Yellow Alternative Spiked Shoe was worn.

The front (left) and back (right) foot conditions are both shown within the above trace. Time of ball impact was identified to gain an understanding of the forces generated throughout the backswing, downswing and follow-through. The greatest force recorded was on the vertical force of the front (left) foot around ball impact. The vertical (Fz) forces were greatest on both the front and back-foot.

Figure 5.6 identifies the different stages of the swing process in relation to the ball impact.

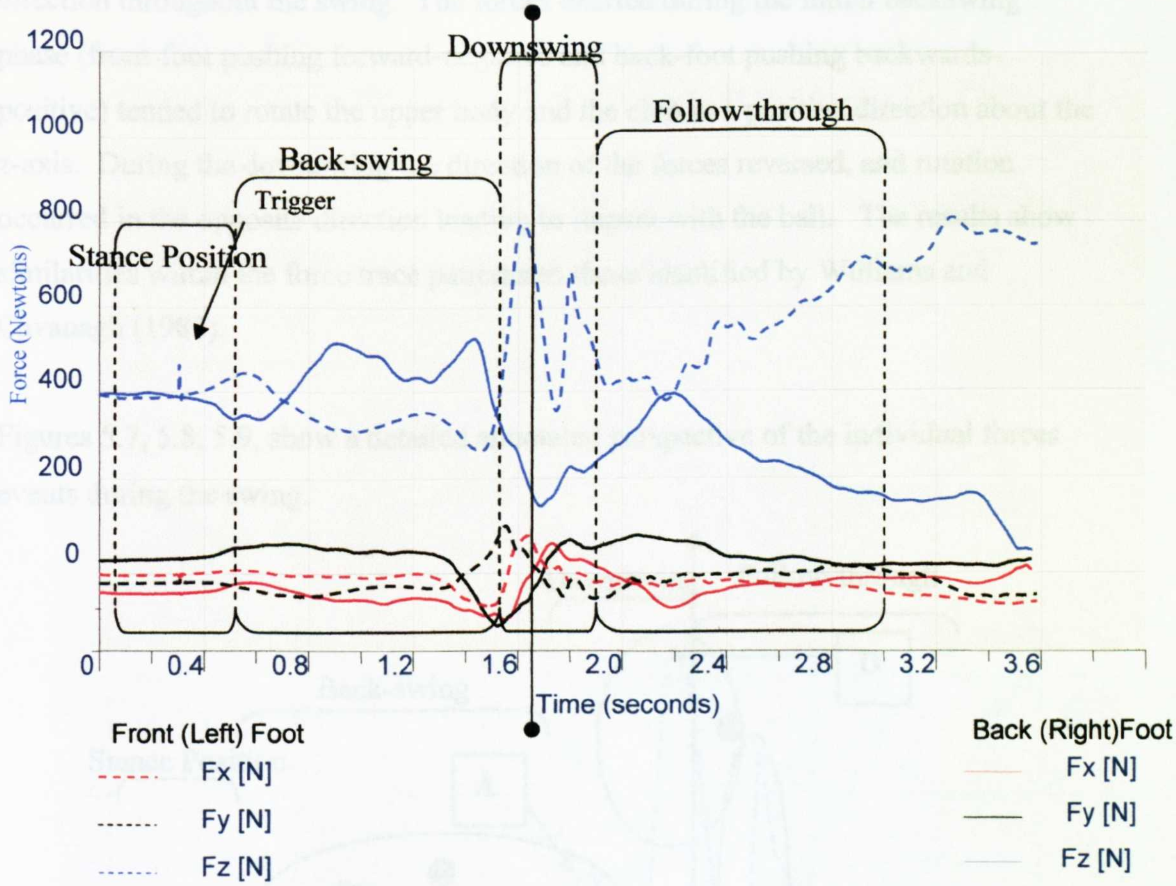


Figure 5.6. Action Force Trace Identifying the Stages of the Golf Swing with a Driver by a Low Handicap Golfer weighing 798N.

During the backswing, the vertical Fz force was transferred onto the back-foot with a rapid transfer onto the front-foot during the downswing prior to ball impact. Peak values just before impact on the front-foot showed the vertical force to be 1.3 times body weight supporting Williams and Cavanagh's (1983) findings who also identified forces greater than the golfers body weight. Dillman and Lange (1994) considered the Fz vertical forces greater than body weight of 798N attributable to the centrifugal forces caused by the swinging club.

At the top of the backswing and until just before impact, the Fx forces were exerted in a negative direction by both feet, with the reaction forces moving the body to the left towards the flag. The direction of force production in both feet was reversed with ball impact, which tended to stop the body movements from right to left.

Mean anteroposterior forces (Fy) showed forces for both feet to be in the opposite direction throughout the swing. The forces exerted during the initial backswing phase (front-foot pushing forward-negative and back-foot pushing backwards-positive) tended to rotate the upper body and the club in a positive direction about the z-axis. During the downswing the direction of the forces reversed, and rotation occurred in the opposite direction leading to impact with the ball. The results show similarities within the force trace patterns to those identified by Williams and Cavanagh (1983).

Figures 5.7, 5.8, 5.9, show a detailed annotated perspective of the individual forces events during the swing.

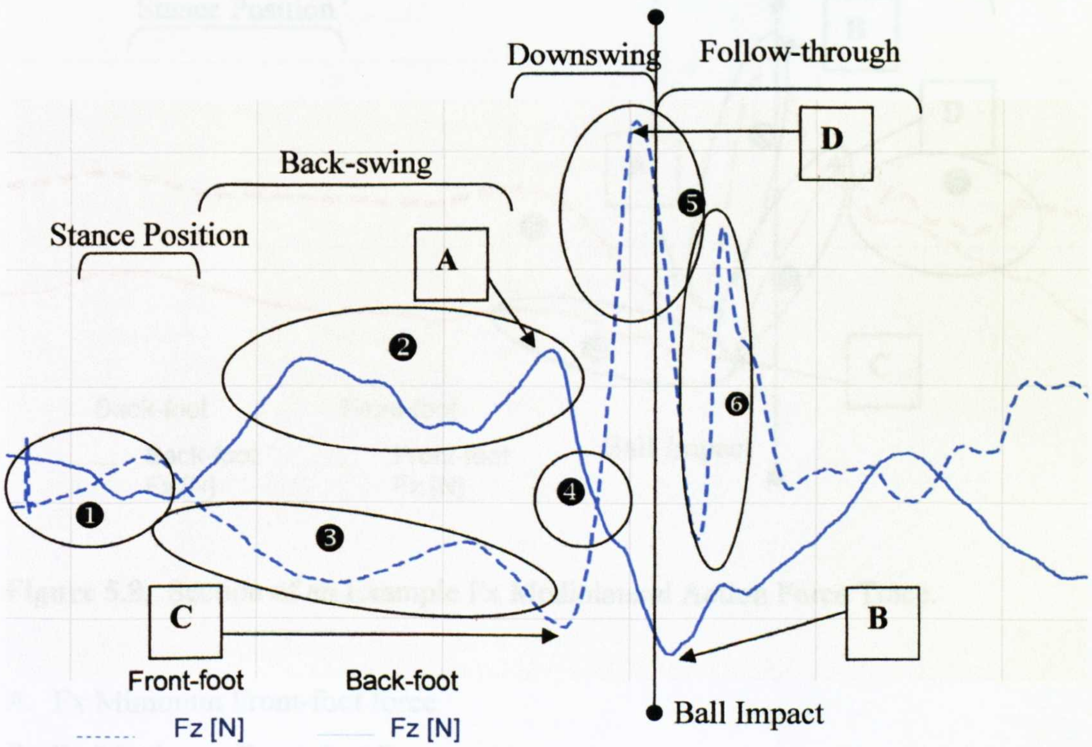


Figure 5.7. Section of an Example Fz Action Force Trace.

A. Fz Maximum Back-foot force
B. Fz Minimum Back-foot force
C. Fz Minimum Front-foot force
D. Fz Maximum Front-foot force

Vertical Event

1. Initial stance phase.
2. Weight positioned onto the back-foot during the backswing.
3. Weight reduction on the front-foot during the backswing.
4. Rapid weight transfer from back-foot to front-foot during the downswing prior to ball impact.
5. Large weight shift onto the front-foot during the downswing and follow-through.
6. The rapid decrease in Fz after ball impact was a result of the upward swing of the golf club pulling the golfer upwards. The front-foot Fz force then increases as the golf club reaches the top of the follow-through re-establishing the golfer's body weight.

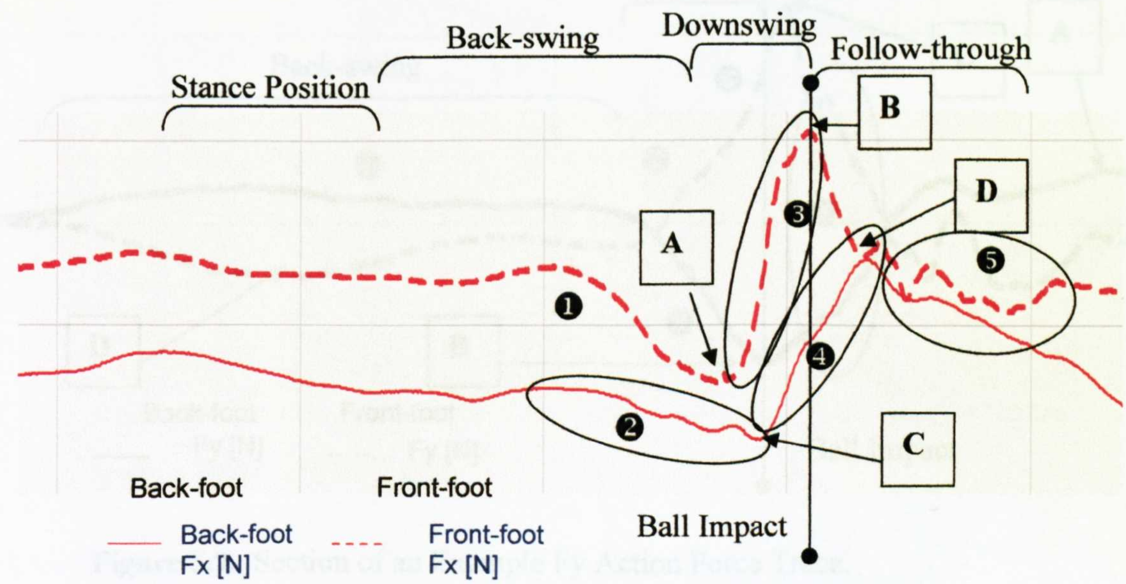


Figure 5.8. Section of an Example Fx Mediolateral Action Force Trace.

A. Fx Minimum Front-foot force

B. Fx Maximum Front-foot force

C. Fx Minimum Back-foot force

D. Fx Maximum Back-foot force

Mediolateral Event

1. Front-foot medial weight transfer towards the back-foot during the backswing.
2. Back-foot maintains stable position with slight lateral movement during the backswing.
3. Front-foot lateral weight transfer during the downswing up to ball impact as the golfer's bodyweight transfers onto the front-foot.
4. Back-foot transfers onto the medial edge of the shoe as the golfer transfers their body weight to the front-foot.
5. Weight distribution plateaus out as the club reaches the end of the swing process across the top of the shoulders.

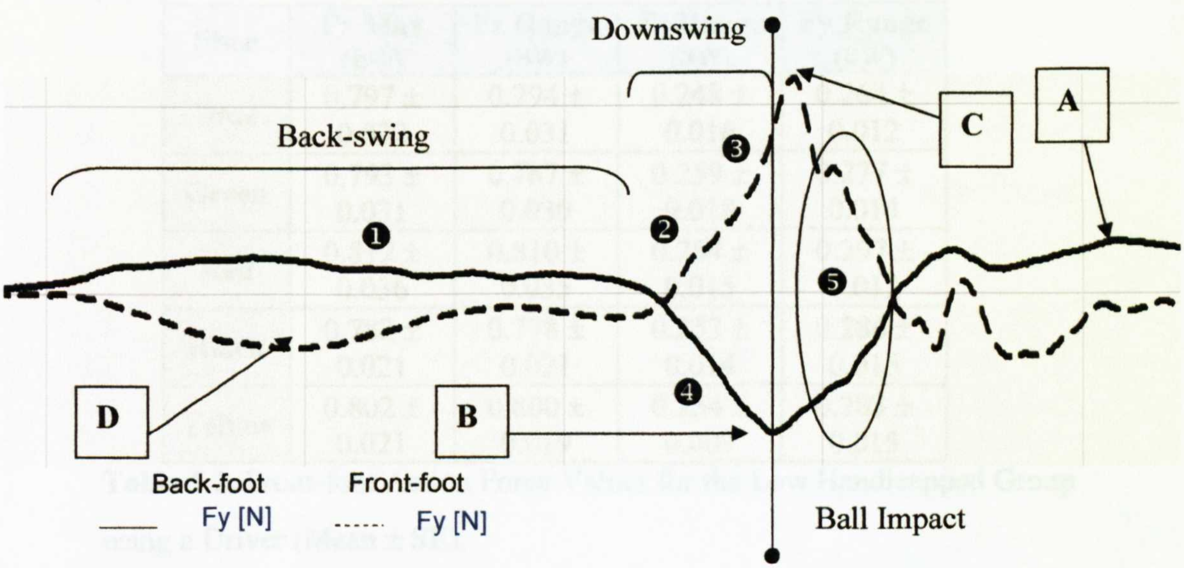


Figure 5.9. Section of an Example Fy Action Force Trace.

A. Fy Maximum Back-foot force
B. Fy Minimum Back-foot force
C. Fy Maximum Front-foot force
D. Fy Minimum Front-foot force

Anterior-Posterior Event

1. Front-foot creates an anterior force coupled with a posterior force within the back-foot during the backswing. This 'couple' created a clockwise rotation of the body.
2. Explosive change in Fy forces at the start of the downswing

3. Front-foot produces a posterior force
4. Back-foot generates an anterior force.

   The 'coupling' of the two feet create a anticlockwise rotation during the fast downswing.
5. After ball impact the feet apply opposite anterior and posterior forces allowing the anticlockwise rotation of the golfer to decelerate in a controlled manor.

Table 5.2 and 5.3 show mean peak front-foot and back-foot Fz forces and front and back-foot Fz, Fx and Fy ranges identified within the low handicap group within the five shoe conditions.

Front (Left) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	0.797 ± 0.032	0.794 ± 0.031	0.248 ± 0.016	0.264 ± 0.012
Green	0.793 ± 0.031	0.787 ± 0.030	0.259 ± 0.018	0.277 ± 0.014
Red	0.812 ± 0.036	0.810 ± 0.035	0.254 ± 0.015	0.297 ± 0.012
Black	0.782 ± 0.021	0.778 ± 0.021	0.253 ± 0.014	0.286 ± 0.016
Yellow	0.802 ± 0.021	0.800 ± 0.019	0.254 ± 0.009	0.283 ± 0.015

Table 5.2. Front-foot Action Force Values for the Low Handicapped Group using a Driver (Mean ± SE).

Back (Right) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	0.501 ± 0.022	0.356 ± 0.032	0.188 ± 0.015	0.136 ± 0.009
Green	0.492 ± 0.024	0.345 ± 0.027	0.191 ± 0.012	0.142 ± 0.012
Red	0.488 ± 0.028	0.328 ± 0.032	0.202 ± 0.018	0.154 ± 0.006
Black	0.482 ± 0.031	0.309 ± 0.044	0.189 ± 0.017	0.147 ± 0.010
Yellow	0.492 ± 0.036	0.359 ± 0.036	0.202 ± 0.021	0.141 ± 0.008

Table 5.3. Back-foot Action Force Values for the Low Handicapped Group using a Driver (Mean ± SE).

The differences in forces applied to the front and back shoes can be clearly identified. The forces applied at the front-foot are consistently higher for the maximum vertical forces and all vertical and horizontal action force ranges illustrating the higher traction requirements of the front-foot shoe. Tables 5.2 and 5.3 highlight the similarity between shoe conditions, with the flat-soled shoe performing favourably with the shoes with traction.

Golf requires large rotary movements throughout the swing process. These rotations occur throughout the golfer's body. To gain an accurate understanding of the shoe ground interaction during the swing, rotational forces occurring at the shoe ground interface were identified. These variables included Tz (Free moment about the centre of pressure), Mz (The vertical moment about the 'Z' axis of the force plate) and COFxy (Co-efficient of friction on the horizontal x and y plane).
Figure 5.10 shows a Mz and Tz rotation trace.

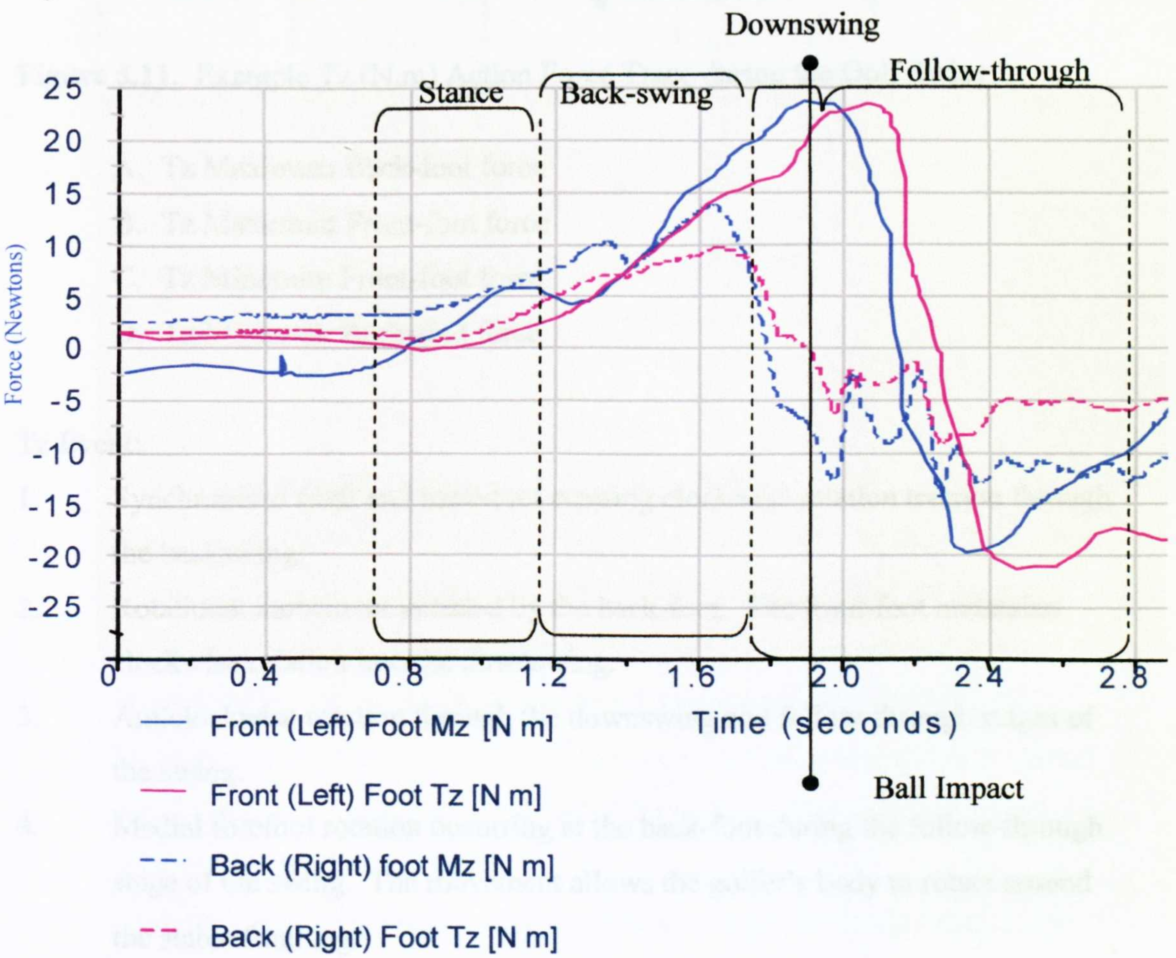


Figure 5.10. Action Force Trace Identifying the Stages of the Golf Swing with a Driver by a Low Handicap Golfer weighing 798N.

Figure 5.11 shows a detailed Tz rotation trace.

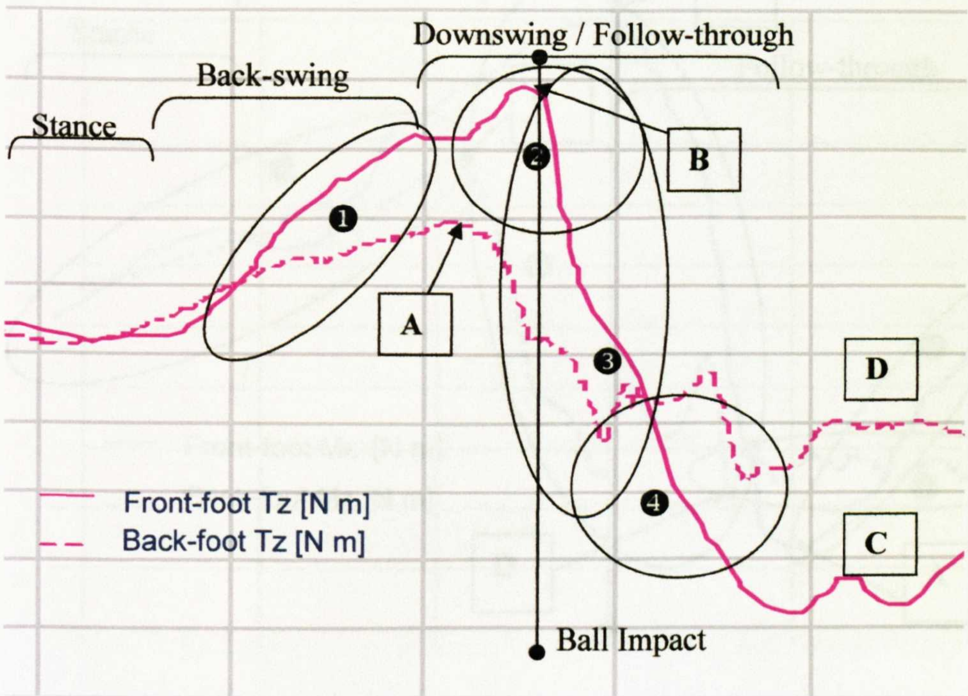


Figure 5.11. Example Tz (N.m) Action Force Trace during the Golf Swing.

A. Tz Maximum Back-foot force

B. Tz Maximum Front-foot force

C. Tz Minimum Front-foot force

D. Tz Minimum Back-foot force

Tz Event:

1. Synchronised front and back-foot creating clockwise rotation traction through the backswing.
2. Rotational movement initiated by the back-foot. The front-foot maintains clockwise rotation into the downswing.
3. Anticlockwise rotation through the downswing and follow-through stages of the swing.
4. Medial forefoot rotation occurring at the back-foot during the follow-through stage of the swing. The movement allows the golfer's body to rotate around the stable front leg.

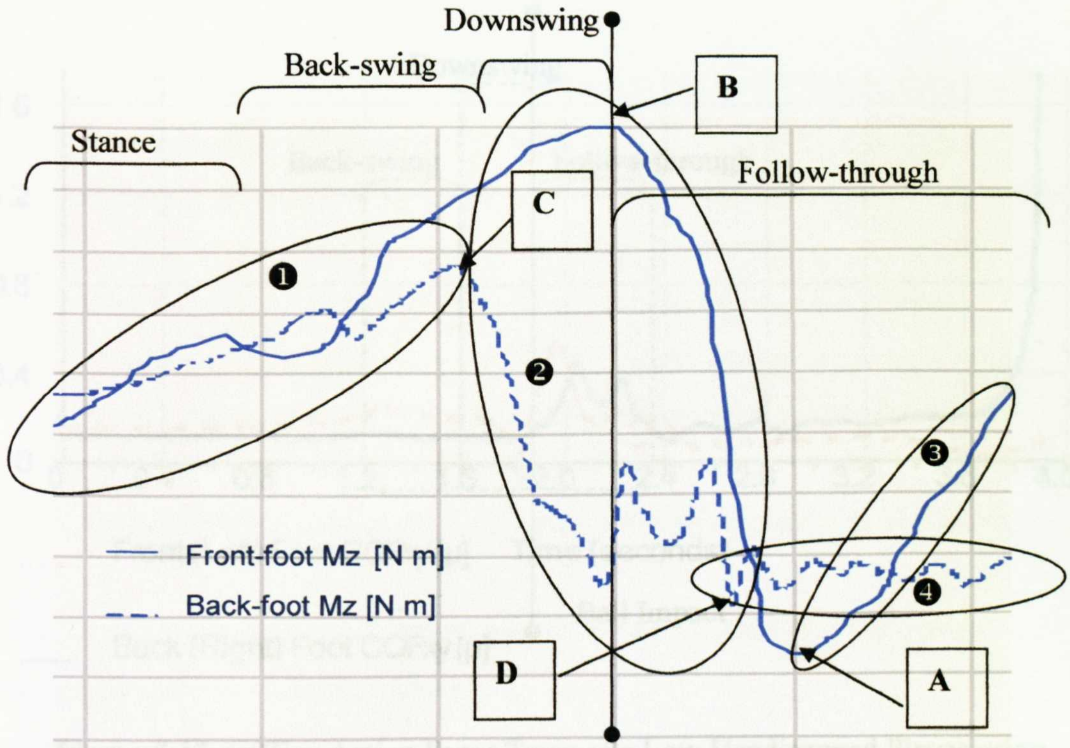


Figure 5.12. Example Mz (N.m) Action Force Trace during the Golf Swing.

A. Mz Minimum Front-foot force

B. Mz Maximum Front-foot force

C. Mz Maximum Back-foot force

D. Mz Minimum Back-foot force

Mz Event

1. Anticlockwise rotation through to the top of the backswing.
2. Rapid clockwise rotation from the top of the backswing into the downswing through ball impact until the top of the follow-through. The low negative troughs between 2 and 3 identify the club head at ball impact where the downward forces are directed towards the target instead of a rotational movement around the front or back legs. As the club passes along the linear plane towards the intended target the club and body start to rotate up and around the front leg.
3. Anticlockwise force applied by the golfer to initiate the deceleration of the swinging club.
4. The back-foot rotates onto the medial forefoot of the shoe allowing the golfer's anticlockwise momentum to rotate around the fixed front leg.

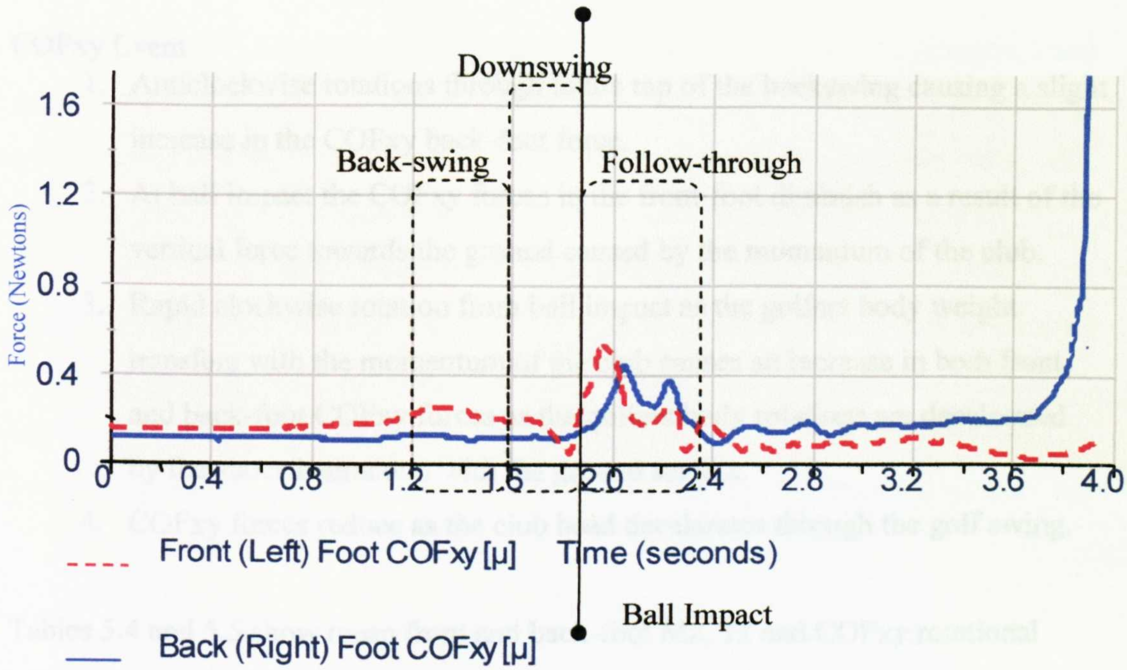


Figure 5.13. COFxy Action Force Trace of a Low Handicapped Player using a Driver.

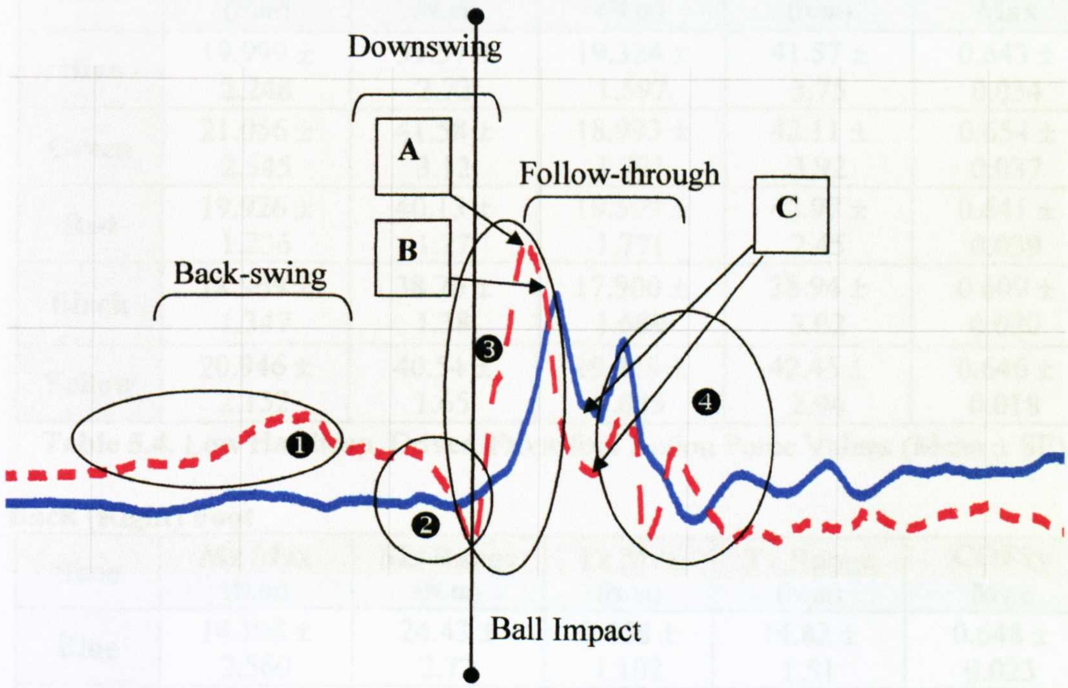


Figure 5.14. Example COFxy Action Force Trace during the Golf Swing.

A. Maximum COFxy Back (Right) foot force
B. Maximum COFxy Front (Left) foot force
C. Front and Back-foot COFxy forces reduce as club produces the highest vertical force during the swing

COFxy Event

1. Anticlockwise rotations through to the top of the backswing causing a slight increase in the COFxy back-foot force.
2. At ball impact the COFxy forces in the front-foot diminish as a result of the vertical force towards the ground caused by the momentum of the club.
3. Rapid clockwise rotation from ball impact as the golfers body weight transfers with the momentum of the club causes an increase in both front and back-foot COFxy forces as the golfers body rotations are decelerated by the shoes interaction with the ground surface.
4. COFxy forces reduce as the club head decelerates through the golf swing.

Tables 5.4 and 5.5 show mean front and back-foot Mz, Tz and COFxy rotational action forces of the low handicap group.

Front (Left) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	19.999 ± 2.248	39.57 ± 2.72	19.324 ± 1.597	41.57 ± 3.75	0.643 ± 0.034
Green	21.056 ± 2.545	41.58 ± 3.12	18.993 ± 1.791	42.11 ± 3.92	0.654 ± 0.037
Red	19.926 ± 1.236	40.13 ± 1.27	19.599 ± 1.771	42.97 ± 2.45	0.641 ± 0.039
Black	18.969 ± 1.347	38.70 ± 1.38	17.900 ± 1.609	38.94 ± 3.02	0.609 ± 0.020
Yellow	20.946 ± 2.152	40.54 ± 1.65	19.459 ± 1.035	42.45 ± 2.94	0.646 ± 0.018

Table 5.4. Low Handicap, Driver, Front-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	14.198 ± 2.560	24.43 ± 2.72	9.458 ± 1.102	14.82 ± 1.51	0.648 ± 0.023
Green	12.194 ± 2.740	24.68 ± 2.54	8.938 ± 1.462	18.22 ± 1.11	0.658 ± 0.040
Red	15.075 ± 3.144	30.04 ± 2.61	8.137 ± 0.564	17.58 ± 1.02	0.620 ± 0.030
Black	12.438 ± 1.805	24.76 ± 2.25	9.416 ± 1.305	14.43 ± 0.87	0.621 ± 0.030
Yellow	15.059 ± 2.458	29.15 ± 3.17	9.623 ± 1.438	15.80 ± 1.32	0.647 ± 0.019

Table 5.5. Low Handicap, Driver, Back-foot Action Force Values (Mean ± SE).

Tables 5.4 and 5.5 identify greater torques within both the Mz and Tz maximum and range front-foot values. The results identified support previous tables in identifying greater torques at the front-foot than at the back-foot during the dynamic swing with a driver. The higher values are a result of the faster more explosive rotations identified during the downswing and follow-through in which the golfer's body weight is transferred onto the front-foot. During this phase the front-foot is required to act as a pivot point for the body and club to rotate and decelerate around. The forces applied by the golfer on the front shoe to control and decelerate their body movements and club result in the higher front-foot Mz and Tz rotational forces.

5.6.1.2: 3iron.

Figure 5.15 illustrates an example Fx, Fy and Fz action force trace of a low handicap player using a 3iron.

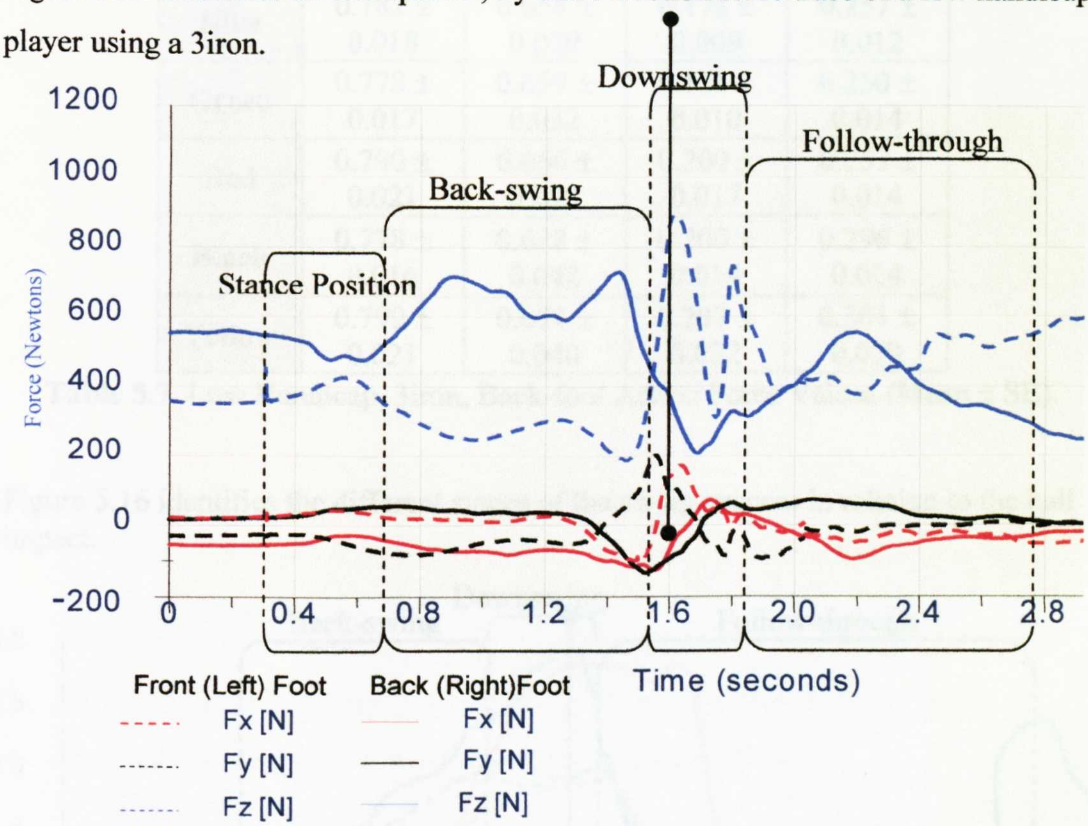


Figure 5.15. Action Force Trace Identifying the Stages of the Golf Swing with a 3iron Club by a Low Handicap Golfer weighing 798N.

Tables 5.6 and 5.7 show mean front-foot and back-foot Fz, Fx and Fy forces developed the low handicapped players within the five shoe conditions using a 3iron club.

Front (Left) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	1.140 ± 0.046	0.930 ± 0.048	0.233 ± 0.006	0.303 ± 0.008
Green	1.115 ± 0.058	0.919 ± 0.055	0.242 ± 0.009	0.309 ± 0.014
Red	1.199 ± 0.078	1.004 ± 0.079	0.245 ± 0.015	0.322 ± 0.008
Black	1.217 ± 0.076	1.062 ± 0.086	0.231 ± 0.009	0.358 ± 0.015
Yellow	1.245 ± 0.077	1.073 ± 0.089	0.225 ± 0.012	0.352 ± 0.008

Table 5.6. Low Handicap, 3iron, Front-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	0.782 ± 0.018	0.658 ± 0.029	0.178 ± 0.009	0.257 ± 0.012
Green	0.778 ± 0.017	0.659 ± 0.032	0.186 ± 0.010	0.250 ± 0.014
Red	0.790 ± 0.021	0.666 ± 0.032	0.200 ± 0.017	0.257 ± 0.014
Black	0.778 ± 0.016	0.628 ± 0.042	0.200 ± 0.014	0.296 ± 0.024
Yellow	0.799 ± 0.021	0.674 ± 0.040	0.207 ± 0.022	0.301 ± 0.029

Table 5.7. Low Handicap, 3iron, Back-foot Action Force Values (Mean ± SE).

Figure 5.16 identifies the different stages of the swing process in relation to the ball impact.

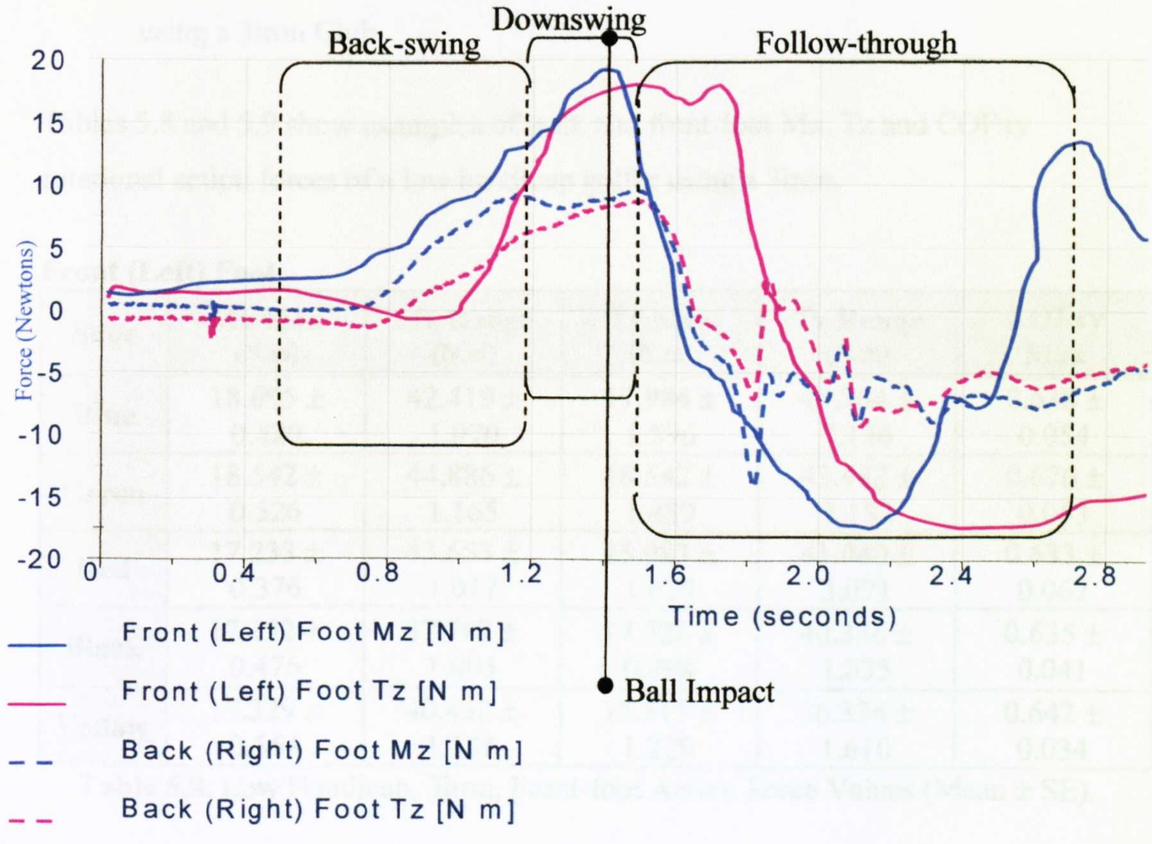


Figure 5.16. Action Force Trace Identifying the Stages of the Golf Swing with a 3iron Golf Club by a Low Handicap Golfer weighing 798N.

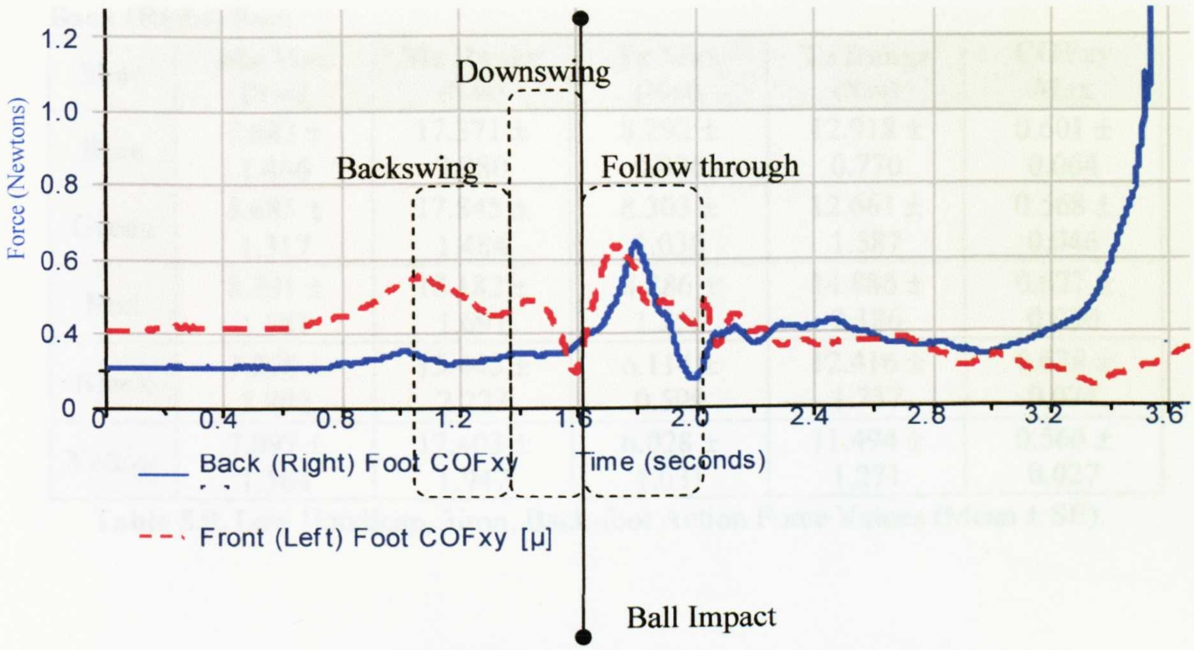


Figure 5.17 Illustrates a COFxy Force Trace of a Low Handicapped Golfer using a 3iron Club.

Tables 5.8 and 5.9 show examples of back and front-foot Mz, Tz and COFxy rotational action forces of a low handicap golfer using a 3iron.

Front (Left) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	18.695 ± 0.420	42.419 ± 1.070	17.984 ± 1.596	43.204 ± 3.136	0.638 ± 0.054
Green	18.542 ± 0.526	44.886 ± 1.165	18.542 ± 1.489	43.442 ± 3.152	0.676 ± 0.053
Red	17.233 ± 0.376	43.653 ± 1.017	15.983 ± 1.675	41.040 ± 3.071	0.633 ± 0.062
Black	17.132 ± 0.476	37.787 ± 1.005	17.728 ± 0.998	40.336 ± 1.035	0.635 ± 0.041
Yellow	17.329 ± 0.564	40.438 ± 1.188	15.515 ± 1.229	36.334 ± 1.610	0.642 ± 0.034

Table 5.8. Low Handicap, 3iron, Front-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	7.683 ± 1.466	17.371 ± 2.280	8.292 ± 0.806	12.918 ± 0.770	0.601 ± 0.064
Green	8.685 ± 1.317	17.845 ± 1.484	8.303 ± 1.030	12.661 ± 1.587	0.568 ± 0.046
Red	8.791 ± 1.781	18.182 ± 1.691	8.886 ± 1.250	14.886 ± 2.186	0.627 ± 0.030
Black	7.276 ± 1.802	15.445 ± 2.223	6.114 ± 0.599	12.416 ± 1.737	0.628 ± 0.074
Yellow	7.097 ± 1.564	17.403 ± 1.947	6.028 ± 1.031	11.494 ± 1.271	0.566 ± 0.027

Table 5.9. Low Handicap, 3iron, Back-foot Action Force Values (Mean ± SE).

5.6.1.3: 7iron.

The following graphs illustrate example traces for a low handicapped golfer using a 7iron golf club. Figure 5.18 identifies the different stages of the swing process in relation to the ball impact.

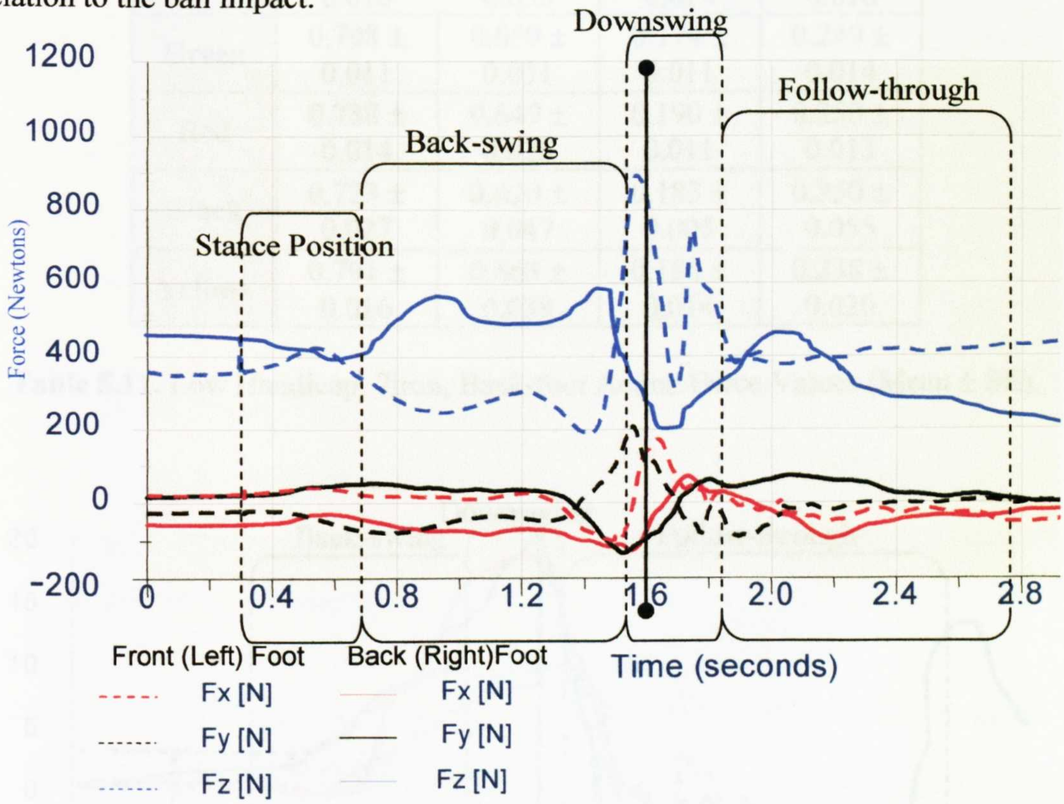


Figure 5.18. Action Force Trace Identifying the Stages of the Golf Swing with a7iron Club by a Low Handicap Golfer weighing 798N.

Tables 5.10 and 5.11 show mean front-foot and back-foot Fz, Fx and Fy forces developed by the low handicapped players within the five shoe conditions.

Front (Left) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	1.075 ± 0.065	0.867 ± 0.071	0.223 ± 0.010	0.288 ± 0.016
Green	1.097 ± 0.061	0.883 ± 0.066	0.223 ± 0.011	0.278 ± 0.008
Red	1.132 ± 0.057	0.930 ± 0.059	0.230 ± 0.009	0.294 ± 0.010
Black	1.102 ± 0.054	0.898 ± 0.057	0.226 ± 0.009	0.283 ± 0.014
Yellow	1.074 ± 0.054	0.871 ± 0.065	0.225 ± 0.008	0.278 ± 0.017

Table 5.10. Low Handicap, 7iron, Front-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	0.791 ± 0.010	0.653 ± 0.035	0.177 ± 0.014	0.251 ± 0.016
Green	0.798 ± 0.011	0.659 ± 0.031	0.174 ± 0.011	0.249 ± 0.014
Red	0.788 ± 0.014	0.649 ± 0.028	0.190 ± 0.011	0.250 ± 0.013
Black	0.723 ± 0.027	0.620 ± 0.047	0.183 ± 0.005	0.250 ± 0.055
Yellow	0.791 ± 0.016	0.663 ± 0.039	0.186 ± 0.014	0.238 ± 0.020

Table 5.11. Low Handicap, 7iron, Back-foot Action Force Values (Mean ± SE).

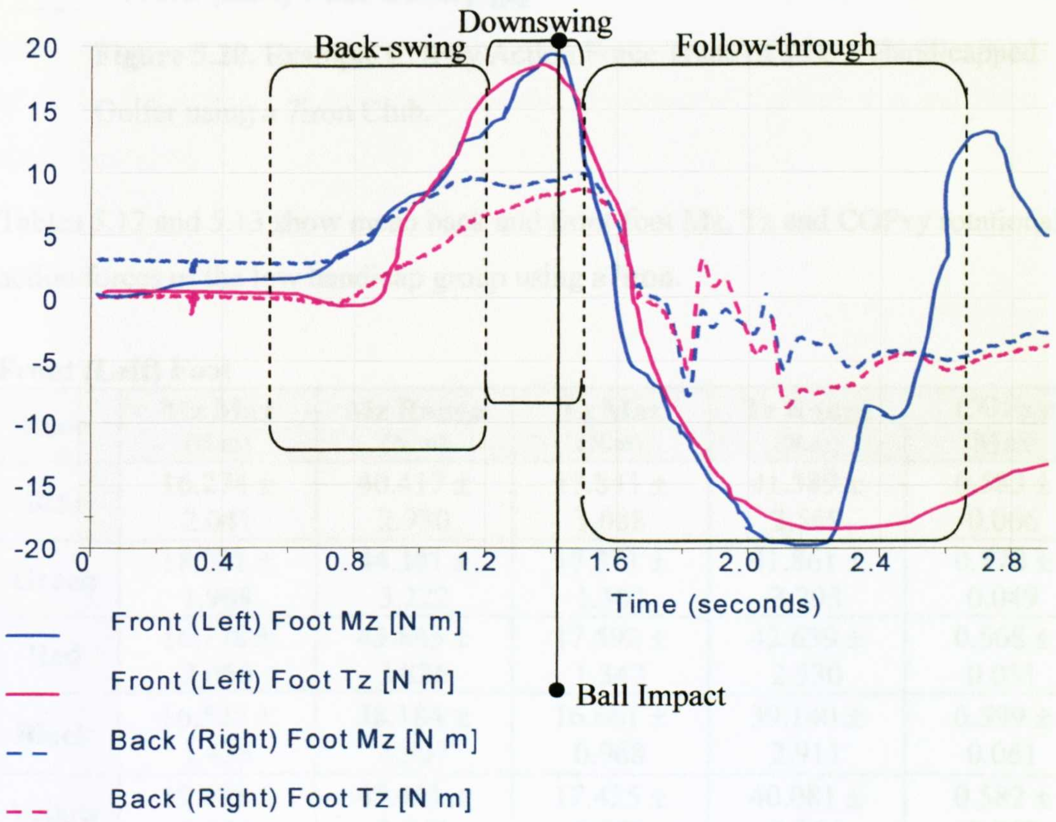


Figure 5.19. Action Force Trace Identifying the Stages of the Golf Swing with a 7iron Golf Club by a Low Handicap Golfer weighing 798N.

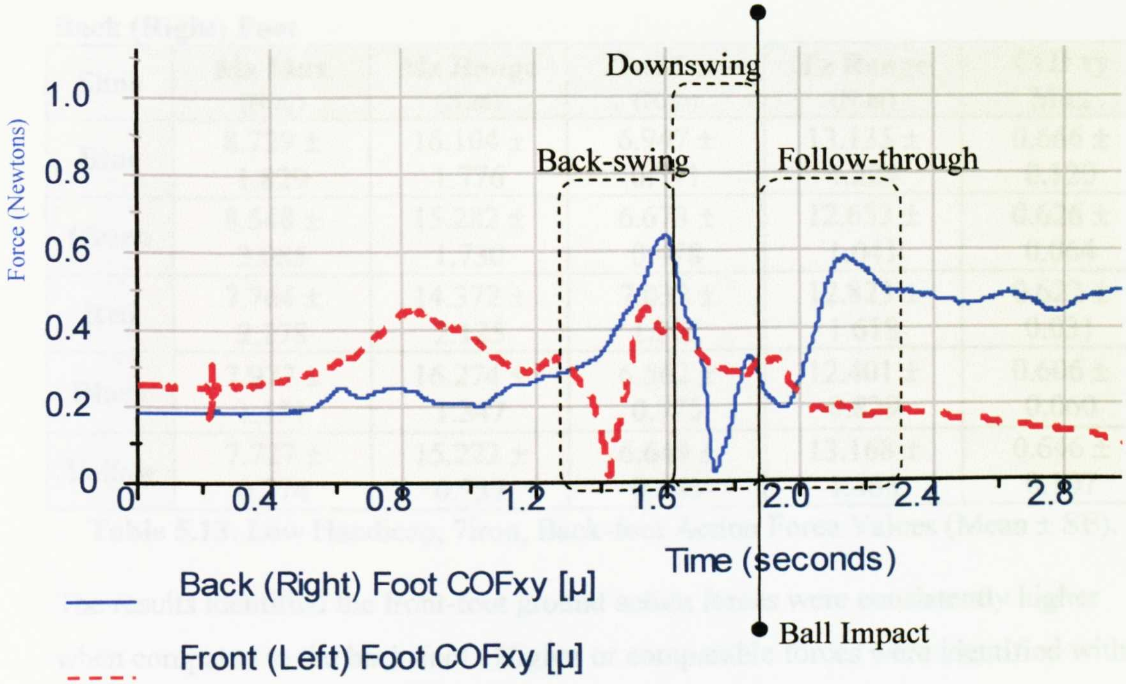


Figure 5.20. Example COFxy Action Force Trace of a Low Handicapped Golfer using a 7iron Club.

Tables 5.12 and 5.13 show mean back and front-foot Mz, Tz and COFxy rotational action forces of the low handicap group using a7iron.

Front (Left) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	16.274 ± 2.041	40.417 ± 2.930	17.841 ± 1.088	41.389 ± 2.569	0.583 ± 0.066
Green	18.031 ± 1.988	44.381 ± 3.222	17.371 ± 1.302	41.861 ± 3.293	0.570 ± 0.049
Red	16.778 ± 2.066	43.845 ± 3.836	17.592 ± 1.342	42.639 ± 2.530	0.568 ± 0.051
Black	16.525 ± 1.438	38.184 ± 1.507	16.661 ± 0.968	39.140 ± 2.911	0.599 ± 0.061
Yellow	19.488 ± 2.926	43.451 ± 3.743	17.425 ± 0.970	40.081 ± 3.314	0.582 ± 0.065

Table 5.12. Low Handicap, 7iron, Front-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	8.729 ± 1.829	16.104 ± 1.776	6.947 ± 0.791	13.135 ± 1.224	0.666 ± 0.120
Green	8.548 ± 2.085	15.282 ± 1.730	6.673 ± 0.478	12.653 ± 1.041	0.626 ± 0.064
Red	7.764 ± 2.278	14.372 ± 2.125	7.032 ± 1.202	12.823 ± 1.618	0.622 ± 0.031
Black	7.977 ± 1.151	16.274 ± 1.347	6.562 ± 0.775	12.401 ± 0.829	0.606 ± 0.060
Yellow	7.727 ± 0.774	15.222 ± 0.937	6.649 ± 0.663	13.168 ± 1.468	0.646 ± 0.107

Table 5.13. Low Handicap, 7iron, Back-foot Action Force Values (Mean ± SE).

The results identified the front-foot ground action forces were consistently higher when compared to the back-foot. Higher or comparable forces were identified within the linear and rotational variables within the driver club condition with the exception of the Fz forces in which higher forces were identified within the 3iron and 7iron club conditions.

Medium Handicap Golfer Example Action Force Traces.

5.6.2.1: Driver.

The following graphs illustrate example traces for a medium handicapped golfer using a driver golf club. Figure 5.21 identifies the different stages of the swing process in relation to the ball impact.

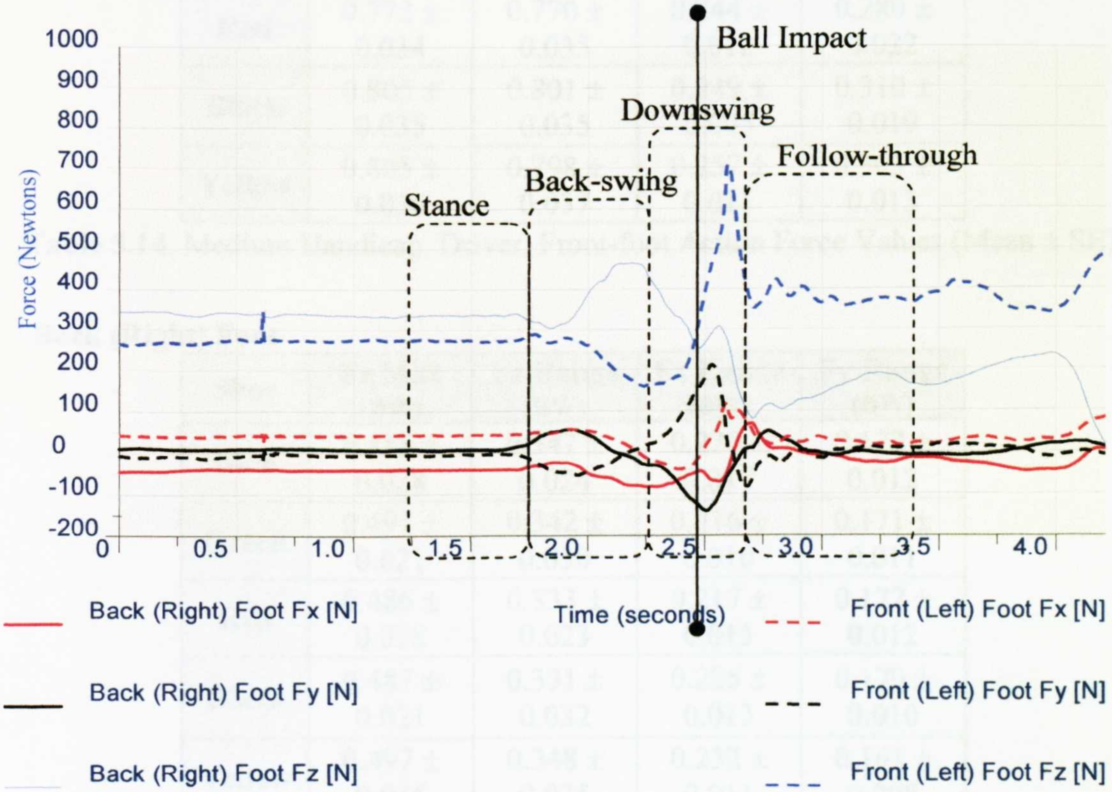


Figure 5.21. Action Force Trace Identifying the Stages of the Golf Swing with a Driver Club by a Medium Handicap Golfer weighing 763N.

Tables 5.14 and 5.15 give mean front-foot and back-foot Fx, Fy and Fz forces developed by a medium handicapped players within the five shoe conditions.

Front (Left) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	0.783 ± 0.036	0.779 ± 0.036	0.267 ± 0.016	0.300 ± 0.015
Green	0.798 ± 0.038	0.792 ± 0.039	0.244 ± 0.012	0.290 ± 0.015
Red	0.772 ± 0.034	0.770 ± 0.035	0.244 ± 0.012	0.280 ± 0.022
Black	0.805 ± 0.035	0.801 ± 0.035	0.249 ± 0.005	0.310 ± 0.019
Yellow	0.805 ± 0.036	0.798 ± 0.037	0.257 ± 0.011	0.303 ± 0.013

Table 5.14. Medium Handicap, Driver, Front-foot Action Force Values (Mean ± SE)

Back (Right) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	0.488 ± 0.028	0.347 ± 0.024	0.220 ± 0.017	0.172 ± 0.012
Green	0.491 ± 0.021	0.342 ± 0.030	0.216 ± 0.010	0.171 ± 0.011
Red	0.486 ± 0.028	0.333 ± 0.023	0.217 ± 0.015	0.177 ± 0.012
Black	0.487 ± 0.021	0.331 ± 0.032	0.225 ± 0.013	0.179 ± 0.010
Yellow	0.497 ± 0.035	0.348 ± 0.035	0.232 ± 0.011	0.161 ± 0.008

Table 5.15. Medium Handicap, Driver, Back-foot Action Force Values (Mean ± SE).

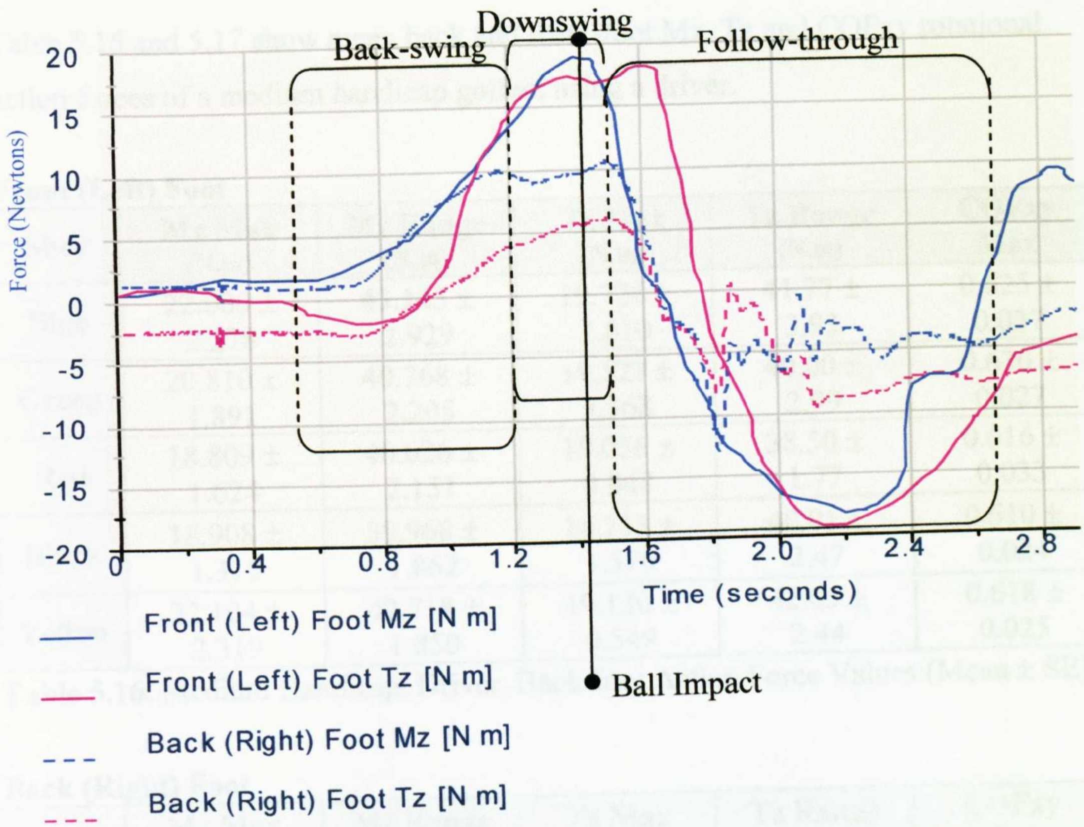


Figure 5.22. Action Force Trace Identifying the Stages of the Golf Swing with a Driver Golf Club by a Medium Handicap Golfer weighing 763N.

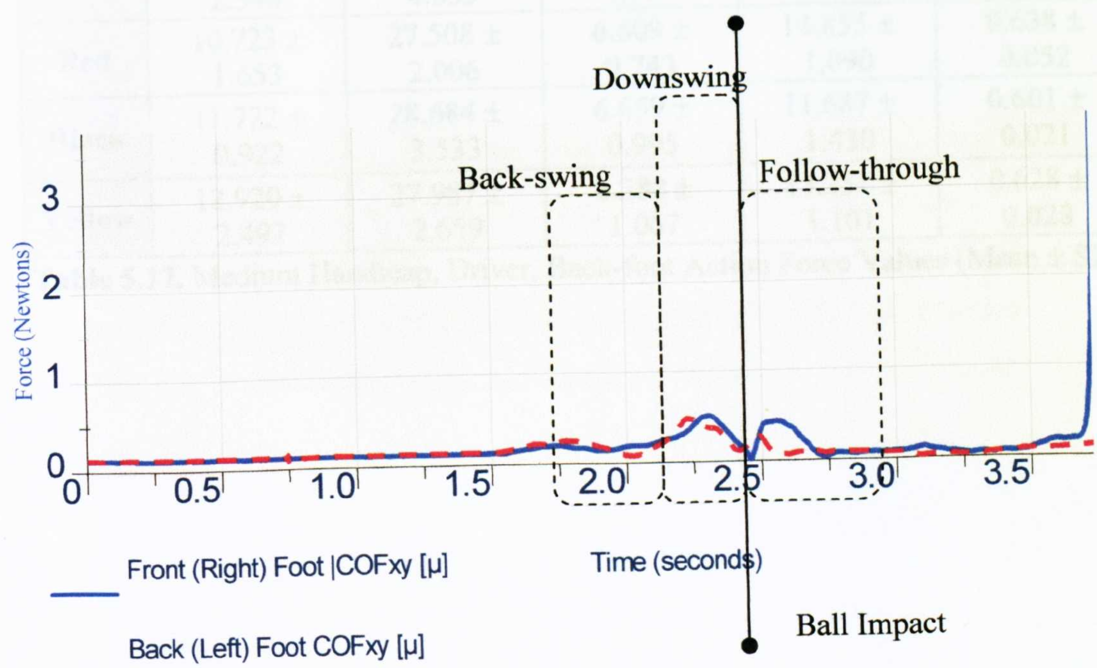


Figure 5.23 Illustrates an Example of a COFxy Trace From a Medium Handicapped Player using a Driver weighing 763N.

Table 5.16 and 5.17 show mean back and front-foot Mz, Tz and COFxy rotational action forces of a medium handicap golfers using a driver.

Front (Left) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	22.000 ± 2.278	43.143 ± 2.929	19.724 ± 2.810	41.77 ± 3.93	0.625 ± 0.037
Green	20.810 ± 1.891	40.768 ± 2.205	19.527 ± 3.368	40.00 ± 2.99	0.630 ± 0.027
Red	18.809 ± 1.624	40.026 ± 2.151	19.056 ± 0.848	38.50 ± 1.77	0.616 ± 0.033
Black	18.908 ± 1.315	39.968 ± 1.862	18.713 ± 1.570	40.01 ± 2.47	0.610 ± 0.024
Yellow	22.104 ± 2.319	42.718 ± 1.850	19.130 ± 0.549	42.05 ± 2.44	0.618 ± 0.025

Table 5.16. Medium Handicap, Driver, Back-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	12.488 ± 1.330	25.436 ± 3.116	7.222 ± 0.999	12.783 ± 1.620	0.623 ± 0.037
Green	12.102 ± 2.348	27.910 ± 4.855	7.690 ± 1.157	15.524 ± 1.682	0.625 ± 0.067
Red	10.723 ± 1.653	27.508 ± 2.006	6.609 ± 0.743	14.855 ± 1.090	0.638 ± 0.052
Black	11.722 ± 0.922	28.684 ± 3.533	6.659 ± 0.995	11.687 ± 1.430	0.601 ± 0.021
Yellow	12.920 ± 2.497	27.987 ± 2.659	6.288 ± 1.067	13.251 ± 1.101	0.628 ± 0.028

Table 5.17. Medium Handicap, Driver, Back-foot Action Force Values (Mean ± SE).

5.6.2.2: 3iron.

The following graphs illustrate example traces for a medium handicapped golfer using a 3iron golf club.

Figure 5.24 identifies the different stages of the swing process in relation to the ball impact.

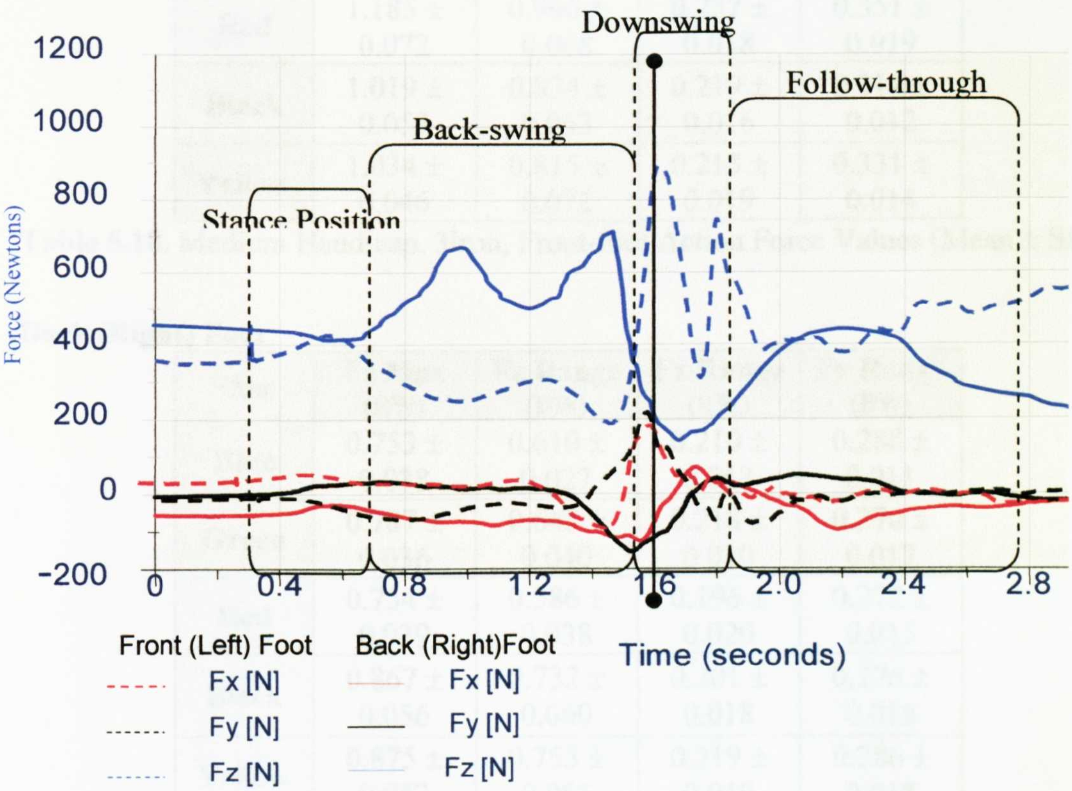


Figure 5.24. Action Force Trace Identifying the Stages of the Golf Swing with a 3iron Club by a Medium Handicap Golfer weighing 763N.

Table 5.18 and 5.19 give mean front-foot and back-foot Fz, Fx and Fy forces developed by a medium handicapped players within the five shoe conditions.

Front (Left) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	1.206 ± 0.071	0.973 ± 0.063	0.213 ± 0.015	0.351 ± 0.014
Green	1.221 ± 0.072	1.021 ± 0.065	0.227 ± 0.013	0.343 ± 0.017
Red	1.185 ± 0.072	0.996 ± 0.068	0.237 ± 0.018	0.351 ± 0.019
Black	1.019 ± 0.052	0.834 ± 0.063	0.219 ± 0.016	0.314 ± 0.012
Yellow	1.034 ± 0.046	0.815 ± 0.072	0.213 ± 0.019	0.331 ± 0.014

Table 5.18. Medium Handicap, 3iron, Front-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	0.753 ± 0.038	0.610 ± 0.027	0.210 ± 0.013	0.288 ± 0.011
Green	0.787 ± 0.036	0.645 ± 0.040	0.218 ± 0.010	0.270 ± 0.017
Red	0.754 ± 0.039	0.586 ± 0.038	0.196 ± 0.020	0.272 ± 0.015
Black	0.867 ± 0.056	0.732 ± 0.060	0.201 ± 0.018	0.276 ± 0.018
Yellow	0.875 ± 0.052	0.755 ± 0.065	0.219 ± 0.019	0.286 ± 0.018

Table 5.19. Medium Handicap, 3iron, Back-foot Action Force Values (Mean ± SE).

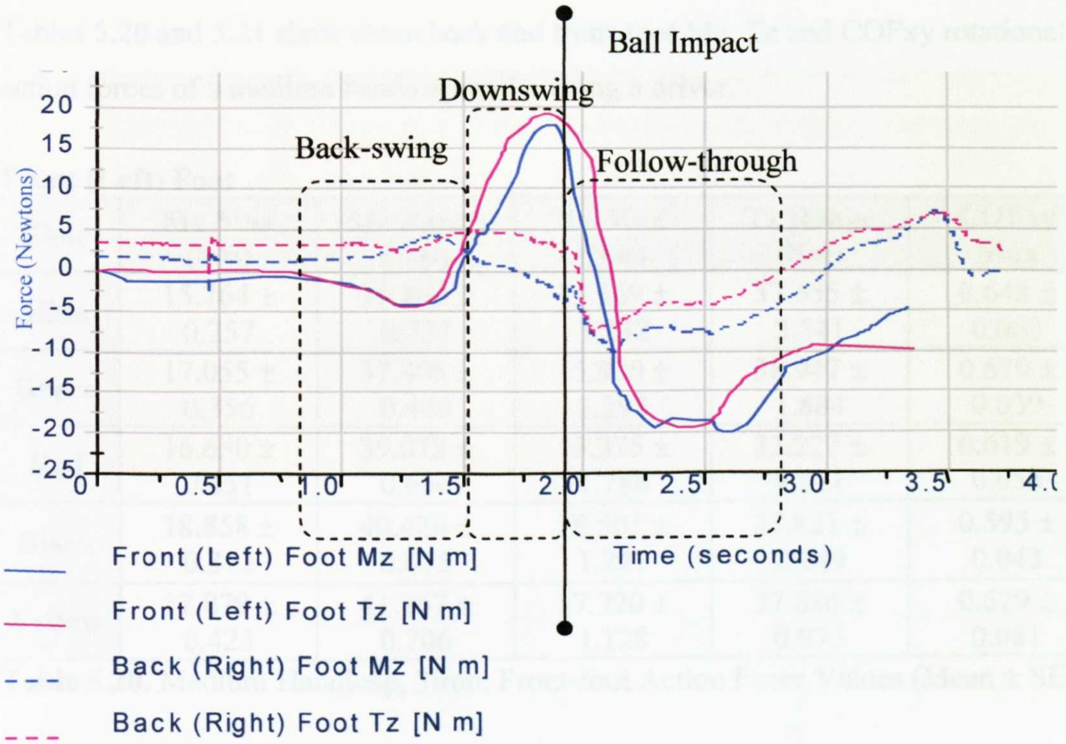


Figure 5.25. Action Force Trace Identifying the Stages of the Golf Swing with a 3iron Golf Club by a Medium Handicap Golfer weighing 763N.

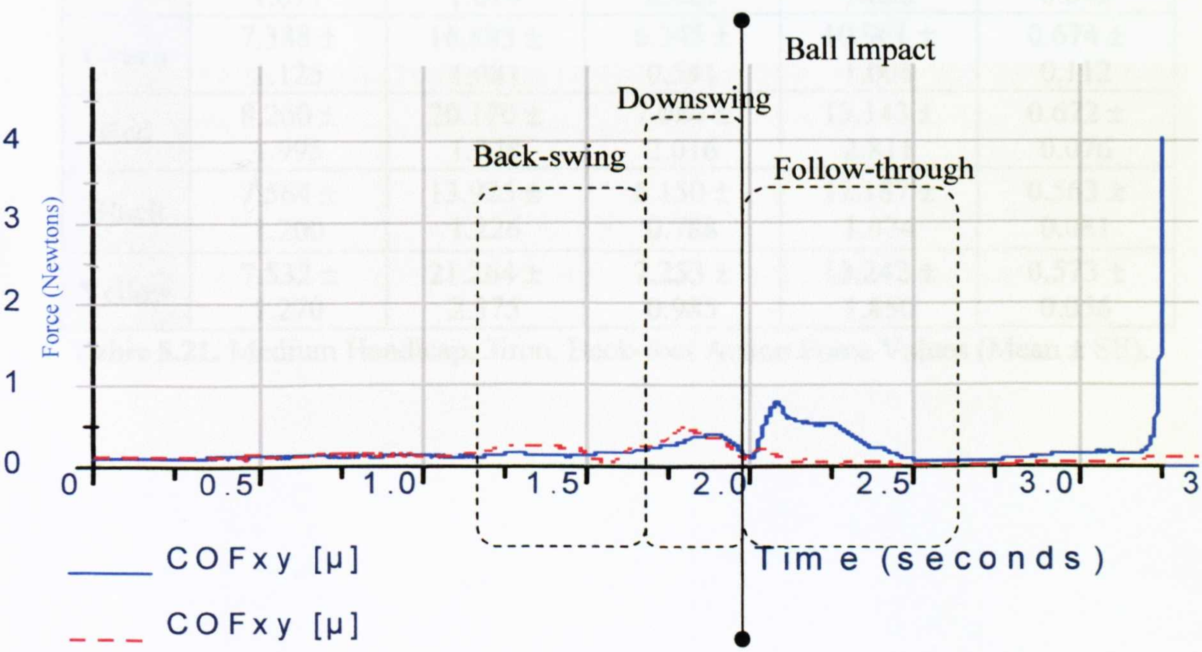


Figure 5.26. COFxy Trace Identifying the Stages of the Golf Swing with a 3iron Golf Club by a Medium Handicap Golfer weighing 763N

Tables 5.20 and 5.21 show mean back and front-foot Mz, Tz and COFxy rotational action forces of a medium handicap golfer using a driver.

Front (Left) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	15.764 ± 0.257	39.862 ± 0.737	15.169 ± 1.232	37.655 ± 2.541	0.648 ± 0.063
Green	17.055 ± 0.356	37.406 ± 0.440	15.930 ± 1.293	38.947 ± 1.884	0.679 ± 0.039
Red	16.650 ± 0.451	39.072 ± 0.656	13.375 ± 1.788	33.227 ± 4.021	0.619 ± 0.055
Black	18.858 ± 0.312	40.426 ± 0.675	18.505 ± 1.241	37.821 ± 2.249	0.595 ± 0.043
Yellow	17.879 ± 0.423	41.267 ± 0.706	17.720 ± 1.128	37.886 ± 0.975	0.629 ± 0.081

Table 5.20. Medium Handicap, 3iron, Front-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	7.822 ± 1.071	17.991 ± 1.619	6.491 ± 0.929	11.001 ± 1.208	0.580 ± 0.043
Green	7.388 ± 1.125	16.885 ± 1.081	6.345 ± 0.541	10.961 ± 1.008	0.674 ± 0.112
Red	8.260 ± 1.995	20.170 ± 1.778	7.084 ± 2.016	13.143 ± 2.811	0.672 ± 0.076
Black	7.564 ± 1.200	13.925 ± 1.226	6.150 ± 0.788	12.187 ± 1.074	0.563 ± 0.081
Yellow	7.532 ± 1.270	21.264 ± 2.375	7.253 ± 0.985	13.242 ± 1.850	0.573 ± 0.056

Table 5.21. Medium Handicap, 3iron, Back-foot Action Force Values (Mean ± SE).

5.6.2.3: 7iron.

The following graphs illustrate example traces for a medium handicapped golfer using a 7iron golf club. Figure 5.27 identifies the different stages of the swing process in relation to the ball impact.

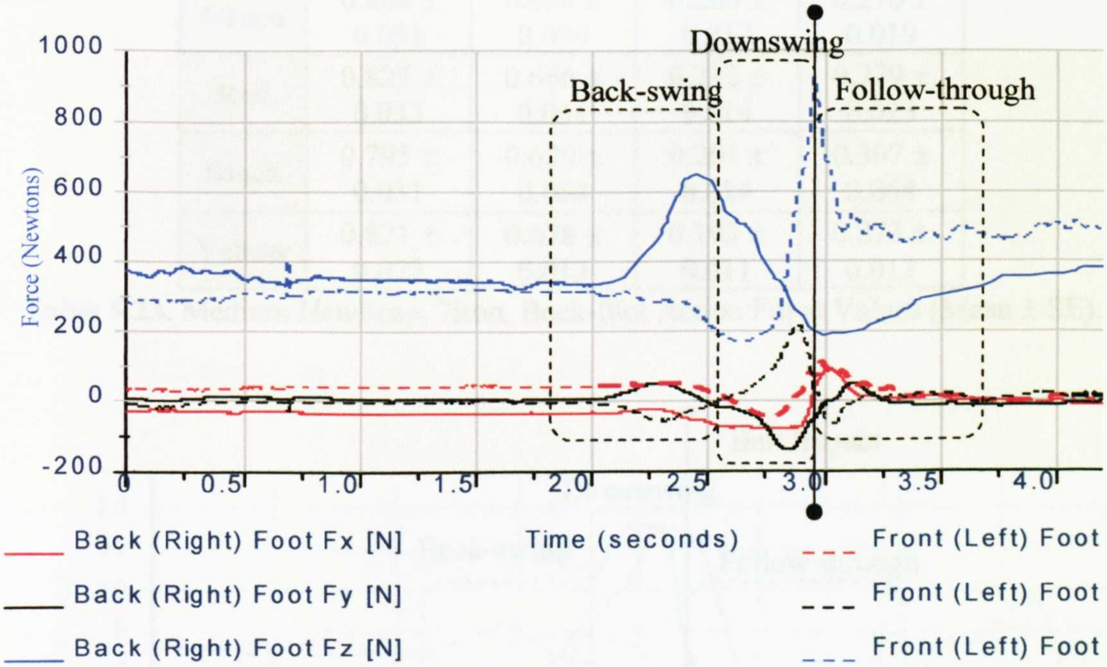


Figure 5.27. Action Force Trace Identifying the Stages of the Golf Swing with a 7iron Club by a Medium Handicap Golfer weighing 763N.

Tables 5.22 and 5.23 show mean front-foot and back-foot Fx, Fy and Fz forces developed by medium-handicapped players within the five shoe conditions.

Front (Left) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	1.057 ± 0.054	0.856 ± 0.051	0.216 ± 0.012	0.342 ± 0.017
Green	1.138 ± 0.080	0.949 ± 0.076	0.212 ± 0.013	0.334 ± 0.011
Red	1.121 ± 0.079	0.942 ± 0.073	0.219 ± 0.010	0.337 ± 0.013
Black	1.112 ± 0.077	0.924 ± 0.067	0.212 ± 0.008	0.333 ± 0.011
Yellow	1.106 ± 0.070	0.913 ± 0.067	0.219 ± 0.011	0.325 ± 0.010

Table 5.22. Medium Handicap, 7iron, Front-foot Action Force Values (Mean ± SE)

Back (Right) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	0.841 ± 0.029	0.676 ± 0.039	0.192 ± 0.009	0.303 ± 0.018
Green	0.808 ± 0.031	0.658 ± 0.034	0.206 ± 0.012	0.270 ± 0.019
Red	0.825 ± 0.033	0.666 ± 0.031	0.212 ± 0.014	0.279 ± 0.023
Black	0.795 ± 0.031	0.629 ± 0.064	0.201 ± 0.014	0.307 ± 0.064
Yellow	0.821 ± 0.022	0.678 ± 0.013	0.193 ± 0.011	0.273 ± 0.013

Table 5.23. Medium Handicap, 7iron, Back-foot Action Force Values (Mean ± SE).

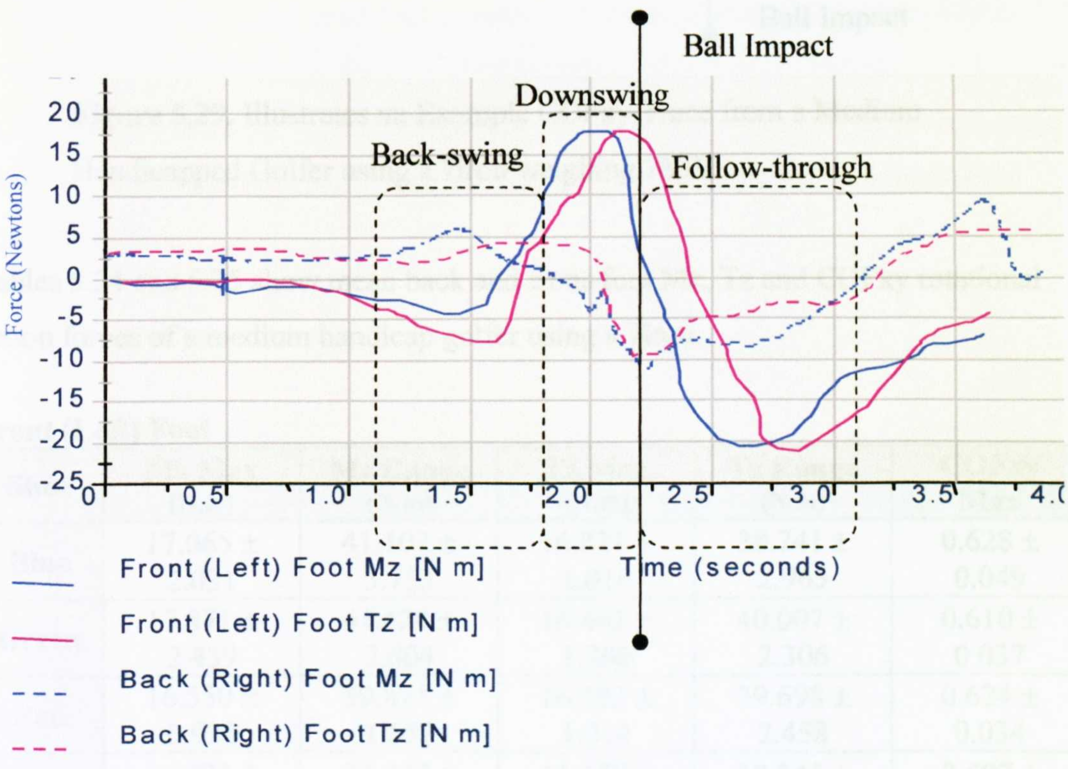


Figure 5.28. Action Force Trace Identifying the Stages of the Golf Swing with a 7iron Golf Club by a Medium Handicap Golfer weighing 763N.

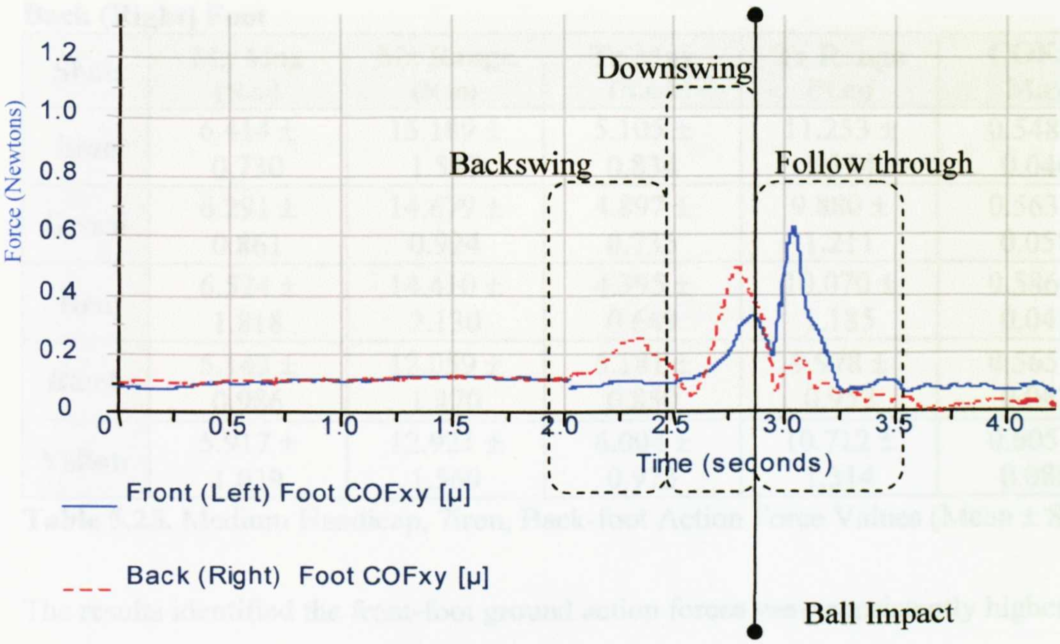


Figure 5.29. Illustrates an Example COFxy Trace from a Medium Handicapped Golfer using a 7iron weighing 763N.

Tables 5.24 and 5.25 show mean back and front-foot Mz, Tz and COFxy rotational action forces of a medium handicap golfer using a 7iron.

Front (Left) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	17.065 ± 2.031	41.102 ± 3.733	16.821 ± 1.016	38.741 ± 2.965	0.628 ± 0.049
Green	17.871 ± 2.439	41.424 ± 2.604	16.865 ± 1.360	40.007 ± 2.306	0.610 ± 0.037
Red	16.550 ± 0.920	39.825 ± 1.657	16.592 ± 1.014	39.698 ± 2.458	0.624 ± 0.034
Black	16.773 ± 1.178	38.807 ± 1.667	16.257 ± 0.970	38.345 ± 1.591	0.597 ± 0.034
Yellow	16.255 ± 1.926	40.930 ± 3.480	16.268 ± 0.713	37.141 ± 2.158	0.720 ± 0.133

Table 5.24. Medium Handicap, 7iron, Front-foot Action Force Values (Mean ± SE)

Back (Right) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	6.414 ± 0.730	15.189 ± 1.537	5.105 ± 0.834	11.253 ± 1.354	0.548 ± 0.046
Green	6.291 ± 0.861	14.679 ± 0.924	4.897 ± 0.735	9.880 ± 1.211	0.563 ± 0.057
Red	6.524 ± 1.818	14.410 ± 2.130	4.395 ± 0.649	10.070 ± 1.185	0.586 ± 0.041
Black	5.143 ± 0.986	12.059 ± 1.470	5.181 ± 0.850	9.978 ± 0.952	0.565 ± 0.042
Yellow	5.917 ± 1.039	12.921 ± 1.569	6.004 ± 0.973	10.712 ± 1.314	0.605 ± 0.086

Table 5.25. Medium Handicap, 7iron, Back-foot Action Force Values (Mean ± SE).

The results identified the front-foot ground action forces were consistently higher when compared to the back-foot. Higher or comparable forces were identified within the linear and rotational variables within the driver club condition with the exception of the Fz forces in which higher forces were identified within the 3iron and 7iron club conditions.

High Handicap Golfer Action Force Traces.

5.6.3.1: Driver.

The following graphs illustrate example traces for a high handicapped golfer using a driver. Figure 5.30 identifies the different stages of the swing process in relation to the ball impact.

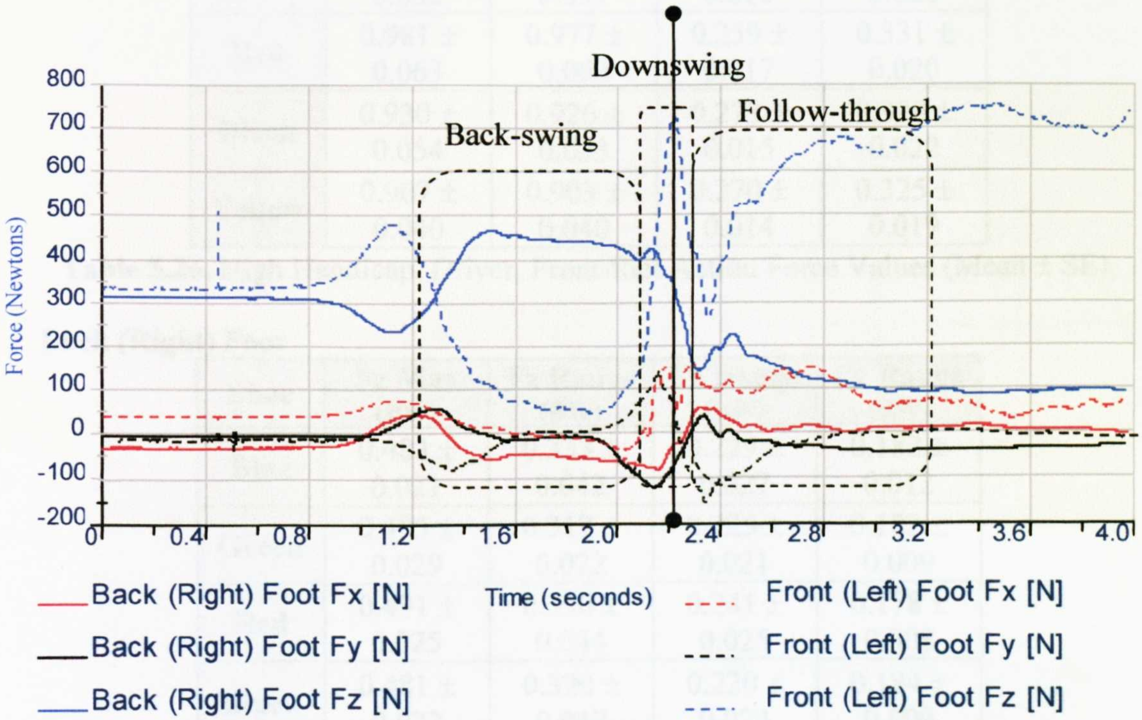


Figure 5.30. Action Force Trace Identifying the Stages of the Golf Swing with a Driver by a High Handicap Golfer weighing 783N.

Tables 5.26 and 5.27 show mean back and front-foot Fz, Fx and Fy action forces of high handicap golfers using a driver.

Front (Left) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	0.902 ± 0.045	0.898 ± 0.044	0.277 ± 0.021	0.338 ± 0.024
Green	0.924 ± 0.032	0.920 ± 0.031	0.253 ± 0.010	0.328 ± 0.020
Red	0.981 ± 0.063	0.977 ± 0.062	0.259 ± 0.017	0.331 ± 0.020
Black	0.930 ± 0.054	0.926 ± 0.053	0.273 ± 0.015	0.320 ± 0.022
Yellow	0.907 ± 0.040	0.903 ± 0.040	0.270 ± 0.014	0.325 ± 0.019

Table 5.26. High Handicap, Driver, Front-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	0.483 ± 0.021	0.333 ± 0.042	0.229 ± 0.027	0.182 ± 0.012
Green	0.495 ± 0.029	0.317 ± 0.022	0.225 ± 0.021	0.182 ± 0.009
Red	0.491 ± 0.025	0.330 ± 0.044	0.241 ± 0.025	0.178 ± 0.008
Black	0.481 ± 0.022	0.320 ± 0.047	0.220 ± 0.024	0.184 ± 0.009
Yellow	0.484 ± 0.039	0.323 ± 0.057	0.248 ± 0.027	0.187 ± 0.008

Table 5.27 High Handicap, Driver, Back-foot Action Force Values (Mean ± SE).

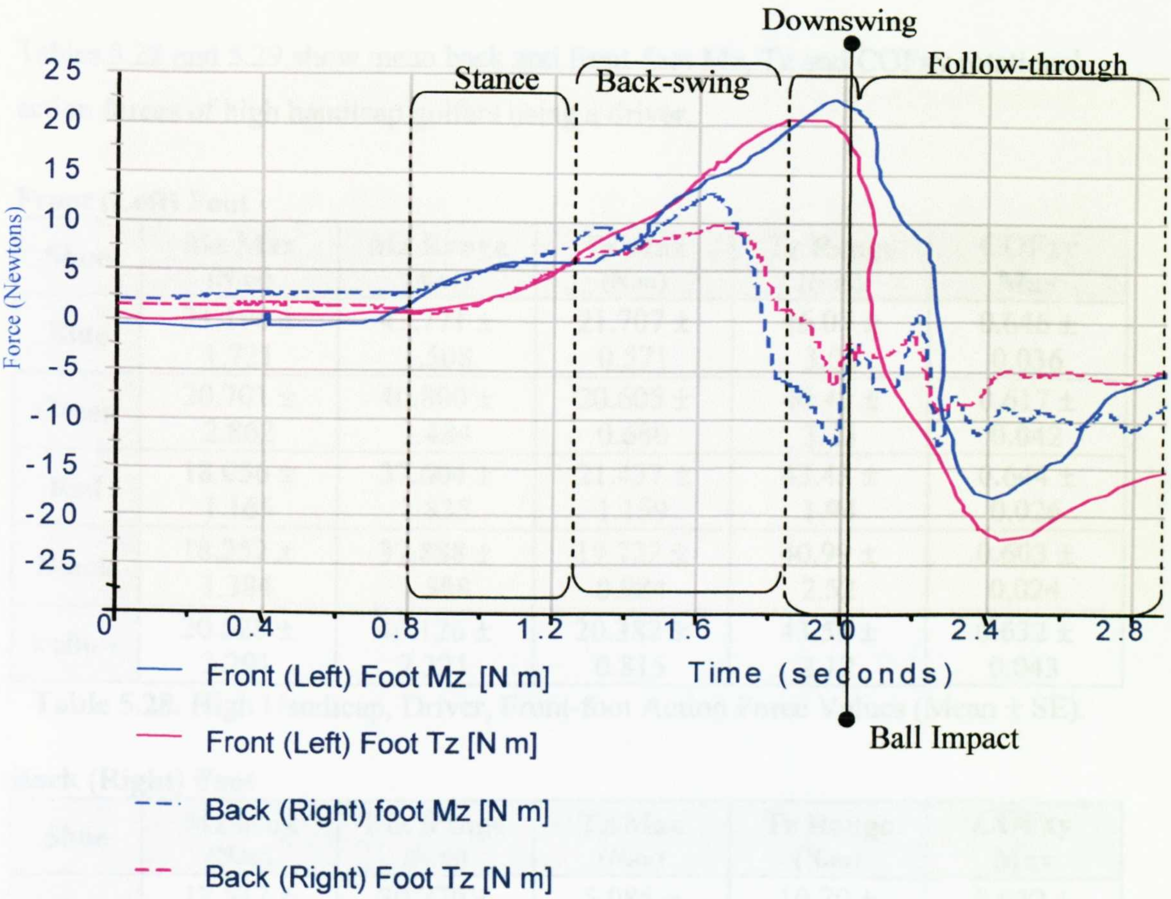


Figure 5.31. Action Force Trace Identifying the Stages of the Golf Swing with a Driver Golf Club by a High Handicap Golfer weighing 783N.

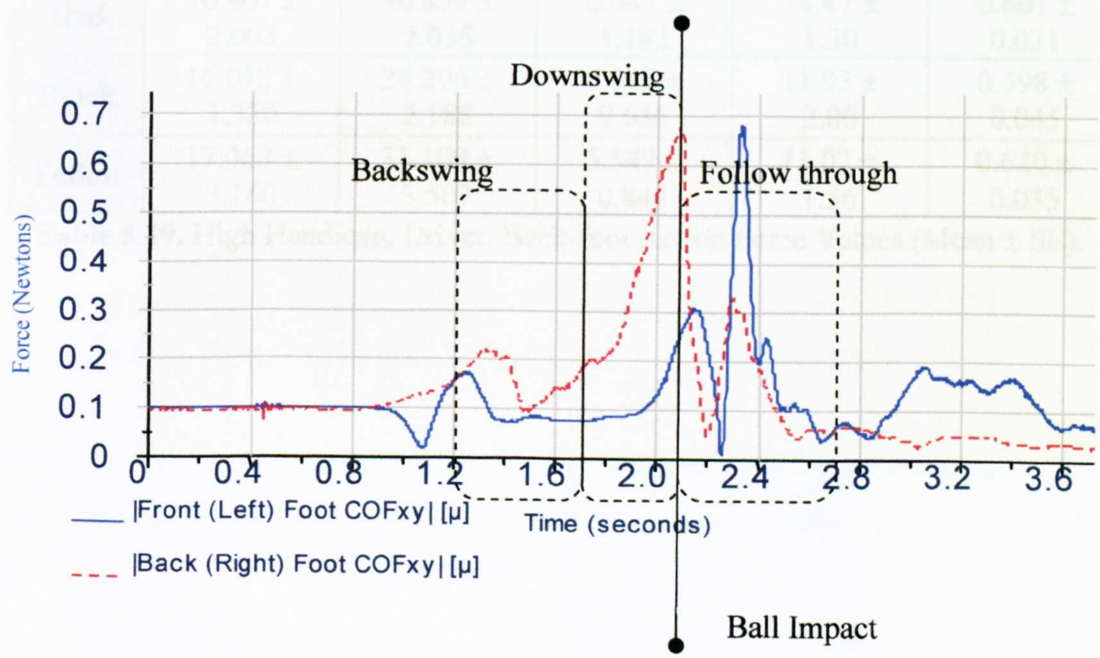


Figure 5.32 Illustrates an Example COFxy Trace of a High Handicapped Golfer using a Driver weighing 783N.

Tables 5.28 and 5.29 show mean back and front-foot Mz, Tz and COFxy rotational action forces of high handicap golfers using a driver.

Front (Left) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	21.196 ± 1.721	43.771 ± 1.508	21.707 ± 0.571	46.07 ± 3.04	0.646 ± 0.036
Green	20.701 ± 2.862	40.800 ± 3.484	20.605 ± 0.680	40.42 ± 3.23	0.617 ± 0.042
Red	18.056 ± 1.165	37.604 ± 1.835	21.437 ± 1.159	43.43 ± 1.94	0.644 ± 0.026
Black	18.252 ± 1.384	37.888 ± 1.588	19.722 ± 0.984	40.99 ± 2.52	0.603 ± 0.024
Yellow	20.528 ± 2.291	40.126 ± 2.321	20.382 ± 0.815	43.58 ± 2.12	0.632 ± 0.043

Table 5.28. High Handicap, Driver, Front-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	17.517 ± 2.727	30.270 ± 2.425	5.085 ± 0.792	10.70 ± 0.89	0.632 ± 0.046
Green	17.710 ± 2.681	31.619 ± 3.212	6.768 ± 1.542	14.21 ± 2.65	0.683 ± 0.032
Red	16.467 ± 2.003	30.854 ± 2.035	6.447 ± 1.182	14.47 ± 1.30	0.601 ± 0.031
Black	16.012 ± 1.330	28.296 ± 2.188	5.918 ± 0.636	11.95 ± 2.00	0.598 ± 0.045
Yellow	17.068 ± 3.160	31.109 ± 3.507	5.549 ± 0.844	11.02 ± 1.56	0.620 ± 0.035

Table 5.29. High Handicap, Driver, Back-foot Action Force Values (Mean ± SE).

5.6.1.2: 3iron.

The following graphs illustrate example traces for a high handicapped golfer using a 3iron golf club.

Figure 5.33 identifies the different stages of the swing process in relation to the ball impact.

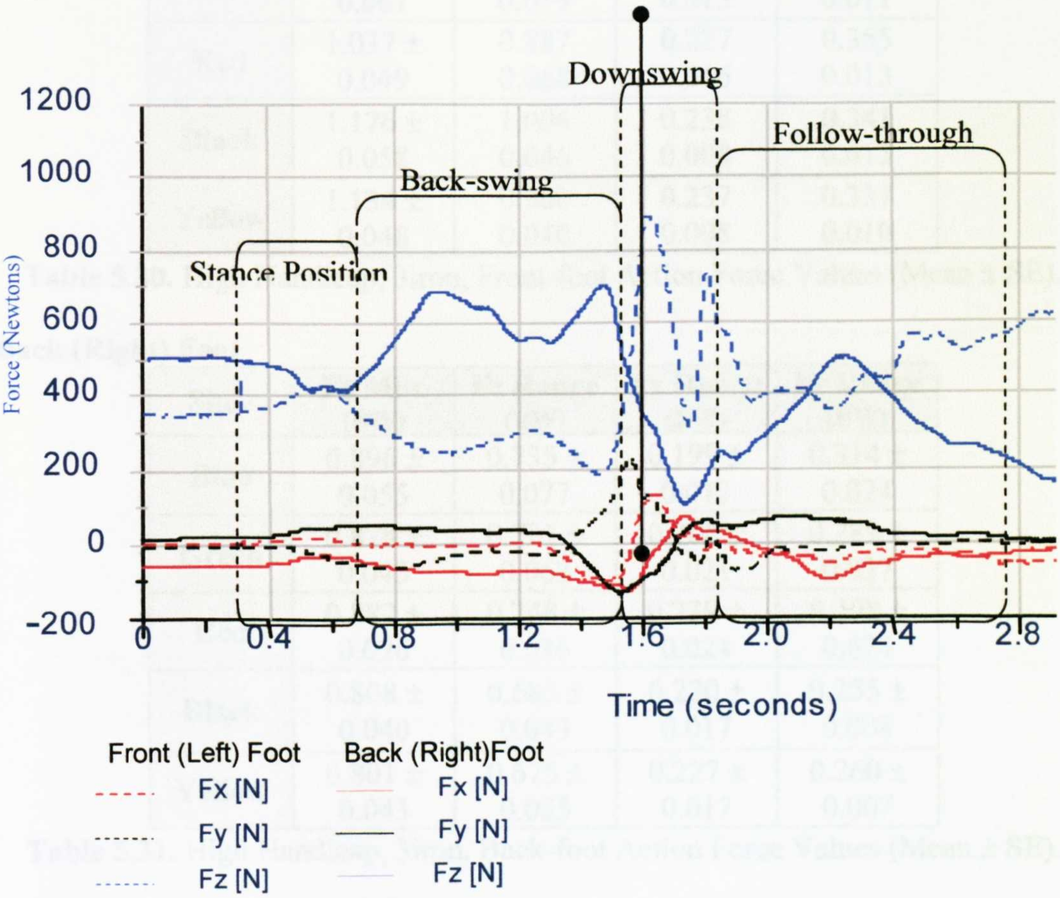


Figure 5.33. Action Force Trace Identifying the Stages of the Golf Swing with a 3iron Club by a High Handicap Golfer weighing 783N.

Table 5.30 and 5.31 show mean front-foot and back-foot Fz, Fx and Fy forces developed by high handicap players within the five shoe conditions.

Front (Left) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	1.095 ± 0.061	0.964 0.072	0.234 0.013	0.361 0.013
Green	1.083 ± 0.067	0.950 0.059	0.226 0.013	0.344 0.011
Red	1.037 ± 0.049	0.887 0.068	0.227 0.016	0.355 0.013
Black	1.176 ± 0.058	1.004 0.046	0.238 0.008	0.341 0.013
Yellow	1.134 ± 0.048	0.960 0.040	0.237 0.008	0.337 0.010

Table 5.30. High Handicap, 3iron, Front-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	0.896 ± 0.055	0.735 ± 0.077	0.199 ± 0.012	0.314 ± 0.024
Green	0.878 ± 0.045	0.721 ± 0.062	0.208 ± 0.021	0.289 ± 0.027
Red	0.882 ± 0.026	0.748 ± 0.036	0.239 ± 0.024	0.298 ± 0.024
Black	0.808 ± 0.040	0.683 ± 0.043	0.220 ± 0.017	0.255 ± 0.008
Yellow	0.801 ± 0.043	0.675 ± 0.055	0.227 ± 0.017	0.260 ± 0.007

Table 5.31. High Handicap, 3iron, Back-foot Action Force Values (Mean ± SE).

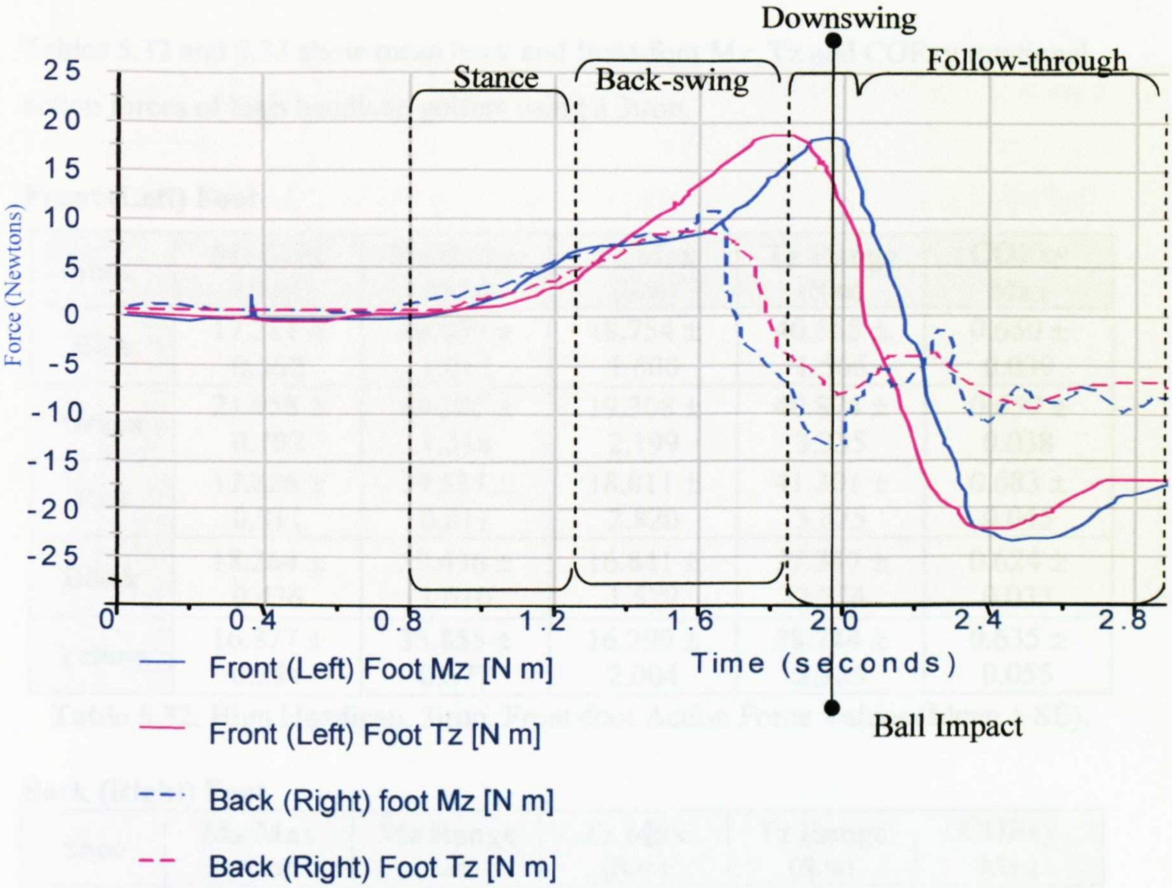


Figure 5.34. Action Force Trace Identifying the Stages of the Golf Swing with a 3iron Golf Club by a High Handicap Golfer weighing 783N.

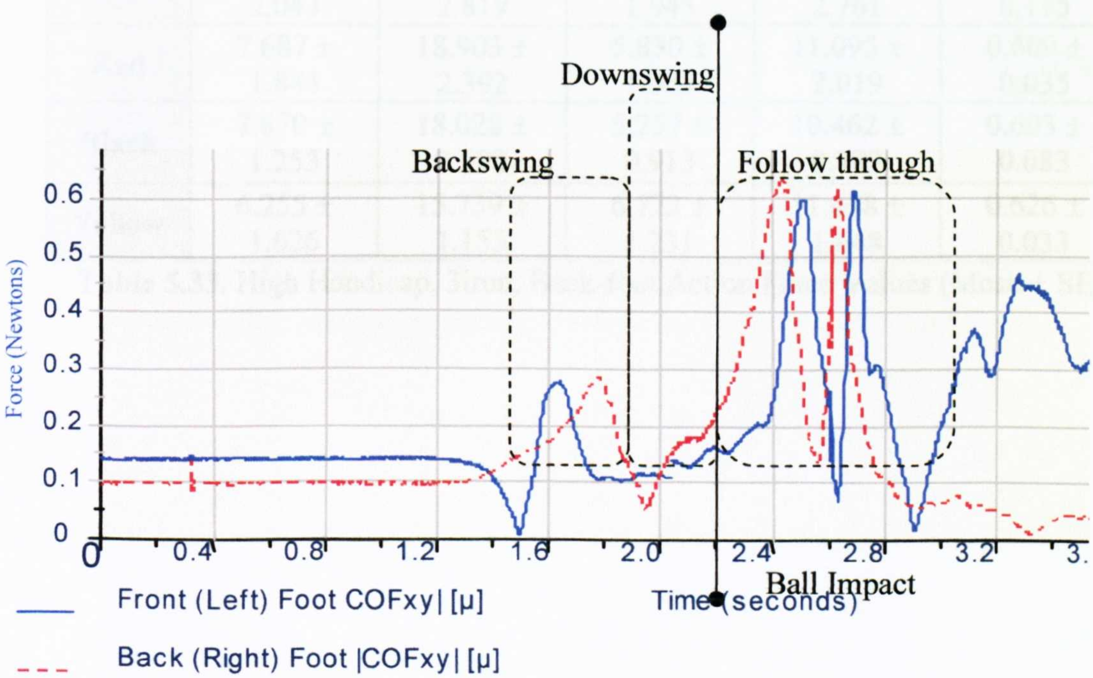


Figure 5.35 Illustrates an Example COFxy Trace from a High Handicapped Golfer using a 3iron weighing 783N.

Tables 5.32 and 5.33 show mean back and front-foot Mz, Tz and COFxy rotational action forces of high handicap golfers using a 3iron.

Front (Left) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	17.211 ± 0.302	40.039 ± 1.012	18.754 ± 1.600	40.555 ± 1.566	0.650 ± 0.039
Green	21.058 ± 0.707	44.205 ± 1.318	19.308 ± 2.199	40.874 ± 3.235	0.657 ± 0.038
Red	17.226 ± 0.311	39.537 ± 0.811	18.811 ± 2.820	41.301 ± 3.875	0.683 ± 0.045
Black	18.284 ± 0.436	39.436 ± 1.010	16.841 ± 1.579	37.387 ± 2.724	0.624 ± 0.033
Yellow	16.877 ± 0.284	35.855 ± 0.677	16.299 ± 2.004	38.744 ± 2.925	0.635 ± 0.055

Table 5.32. High Handicap, 3iron, Front-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	6.461 ± 1.116	16.643 ± 1.639	6.021 ± 0.487	11.898 ± 1.432	0.661 ± 0.070
Green	6.842 ± 2.043	16.655 ± 2.819	5.811 ± 1.045	12.708 ± 2.761	0.605 ± 0.115
Red	7.687 ± 1.844	18.903 ± 2.392	5.830 ± 1.063	11.095 ± 2.019	0.609 ± 0.035
Black	7.870 ± 1.253	18.028 ± 2.592	5.257 ± 0.913	10.462 ± 0.789	0.603 ± 0.083
Yellow	6.255 ± 1.626	15.739 ± 1.155	6.722 ± 1.231	11.638 ± 1.648	0.626 ± 0.033

Table 5.33. High Handicap, 3iron, Back-foot Action Force Values (Mean ± SE).

5.6.3.3: 7iron.

The following graphs illustrate example traces for a high handicapped golfer using a 7iron golf club.

Figure 5.36 identifies the different stages of the swing process in relation to the ball impact.

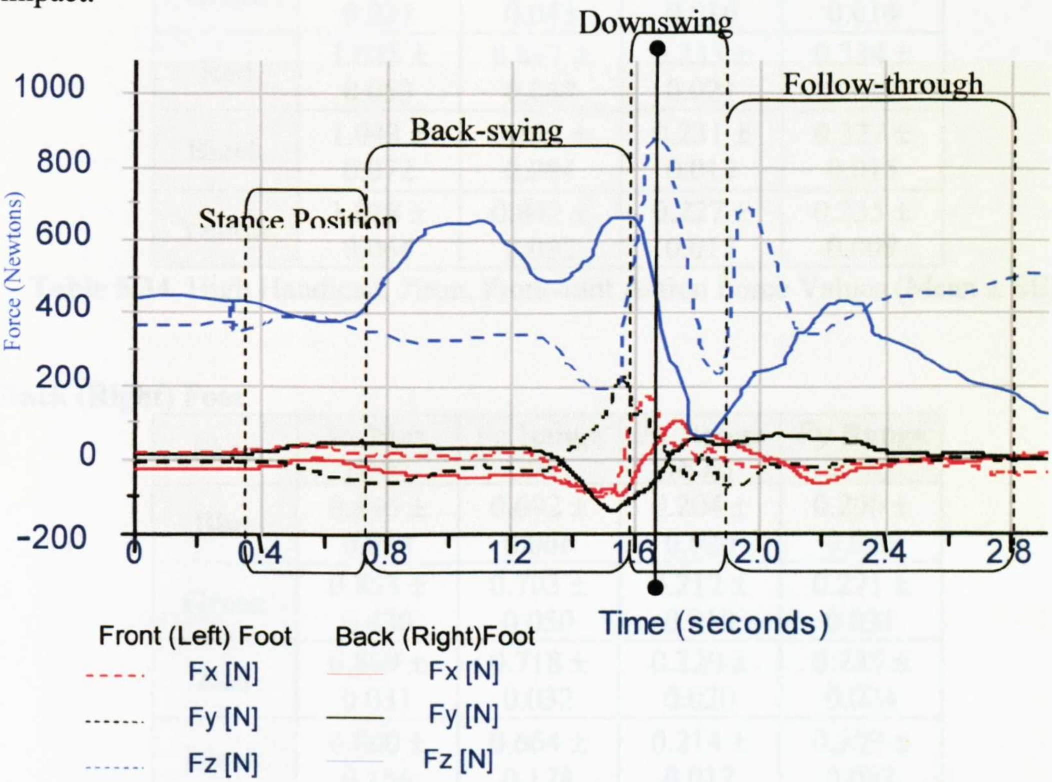


Figure 5.36. Action Force Trace Identifying the Stages of the Golf Swing with a 7iron Club by a High Handicap Golfer weighing 783N.

Tables 5.34 and 5.35 give mean front-foot and back-foot Fx, Fy and Fz forces developed by high handicapped players within the five shoe conditions.

Front (Left) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (BW)	Fy Range (BW)
Blue	1.057 ± 0.053	0.910 ± 0.062	0.214 ± 0.012	0.328 ± 0.021
Green	1.087 ± 0.037	0.943 ± 0.043	0.234 ± 0.016	0.329 ± 0.014
Red	1.045 ± 0.053	0.897 ± 0.068	0.235 ± 0.021	0.334 ± 0.017
Black	1.043 ± 0.072	0.892 ± 0.084	0.231 ± 0.013	0.327 ± 0.015
Yellow	1.018 ± 0.064	0.842 ± 0.092	0.227 ± 0.017	0.335 ± 0.009

Table 5.34. High Handicap, 7iron, Front-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Fz Max (BW)	Fz Range (BW)	Fx Range (N.m)	Fy Range (BW)
Blue	0.845 ± 0.034	0.692 ± 0.066	0.204 ± 0.020	0.296 ± 0.026
Green	0.853 ± 0.030	0.703 ± 0.050	0.212 ± 0.018	0.271 ± 0.021
Red	0.869 ± 0.031	0.718 ± 0.032	0.220 ± 0.020	0.285 ± 0.024
Black	0.800 ± 0.166	0.664 ± 0.178	0.214 ± 0.017	0.209 ± 0.033
Yellow	0.839 ± 0.036	0.675 ± 0.046	0.203 ± 0.019	0.305 ± 0.019

Table 5.35. High Handicap, 7iron, Back-foot Action Force Values (Mean ± SE).

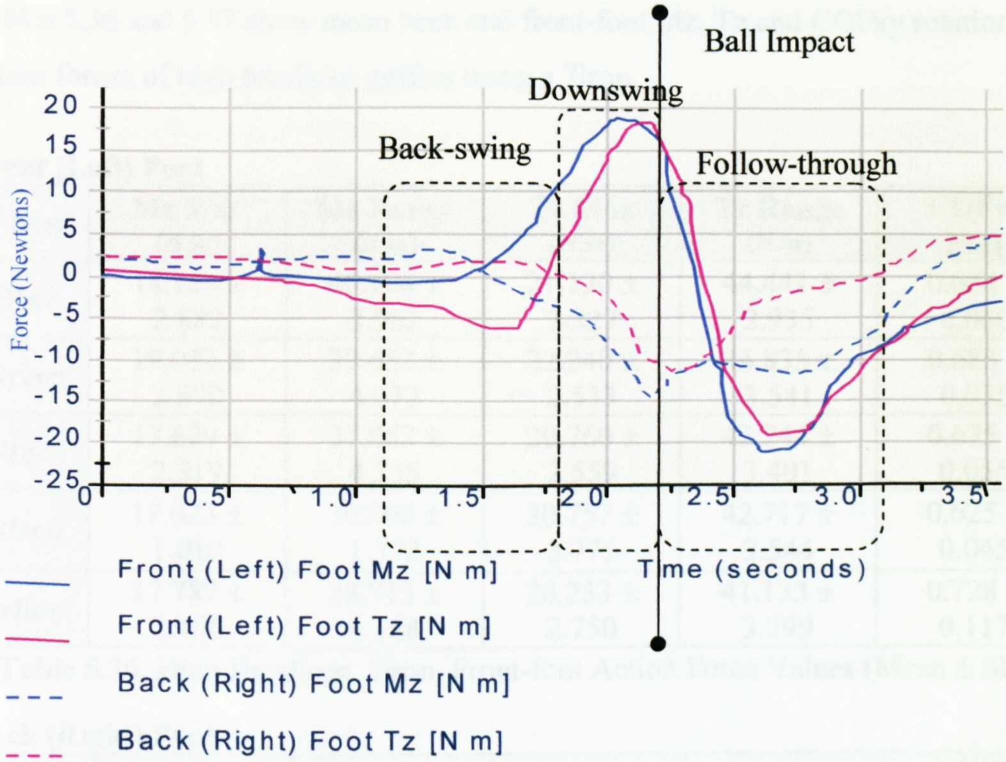


Figure 5.37. Action Force Trace Identifying the Stages of the Golf Swing with a 7iron Golf Club by a High Handicap Golfer weighing 783N.

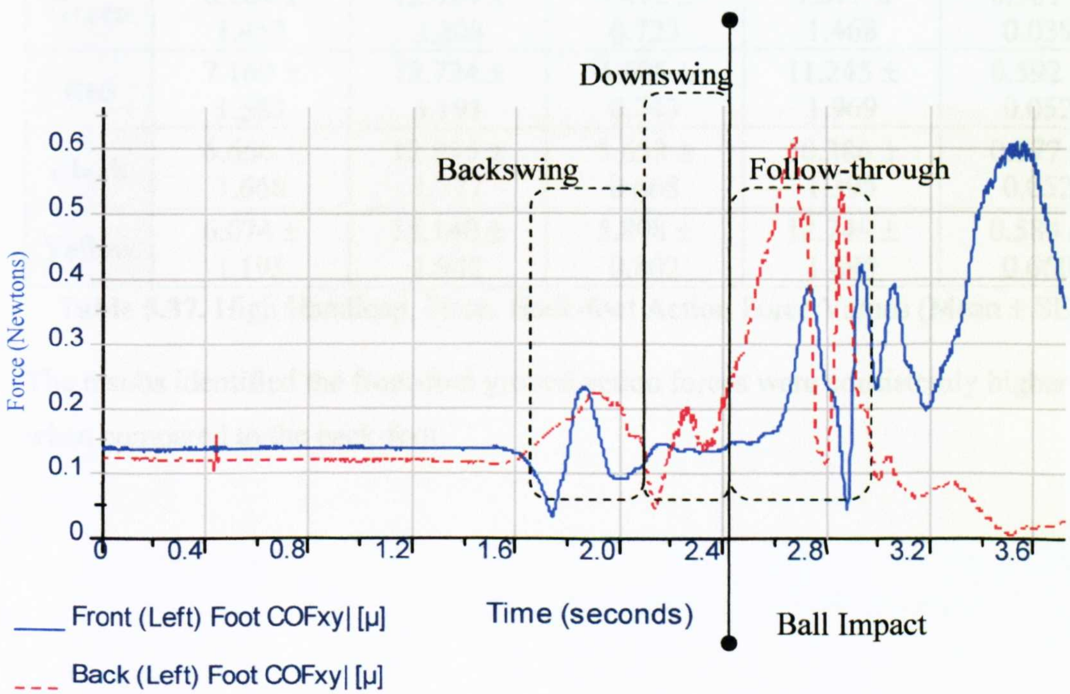


Figure 5.38 Illustrates an Example of a High Handicapped Golfer using a 7iron COFxy Trace weighing 783N.

Tables 5.36 and 5.37 show mean back and front-foot Mz, Tz and COFxy rotational action forces of high handicap golfers using a 7iron.

Front (Left) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	18.154 ± 2.882	40.904 ± 3.962	21.120 ± 2.227	44.441 ± 2.935	0.654 ± 0.060
Green	19.032 ± 2.870	39.652 ± 4.072	22.240 ± 2.533	44.835 ± 3.541	0.685 ± 0.035
Red	17.629 ± 2.319	37.862 ± 4.235	20.760 ± 2.559	42.244 ± 3.401	0.675 ± 0.055
Black	17.023 ± 1.010	39.000 ± 1.372	20.757 ± 2.775	42.717 ± 3.544	0.625 ± 0.045
Yellow	17.787 ± 2.486	38.713 ± 4.188	20.253 ± 2.750	41.133 ± 3.799	0.728 ± 0.117

Table 5.36. High Handicap, 7iron, Front-foot Action Force Values (Mean ± SE).

Back (Right) Foot

Shoe	Mz Max (N.m)	Mz Range (N.m)	Tz Max (N.m)	Tz Range (N.m)	COFxy Max
Blue	6.440 ± 1.420	15.893 ± 2.376	5.592 ± 0.720	11.725 ± 2.144	0.675 ± 0.075
Green	6.284 ± 1.452	12.924 ± 2.203	5.412 ± 0.723	9.577 ± 1.468	0.581 ± 0.039
Red	7.169 ± 1.583	18.724 ± 3.191	4.605 ± 0.743	11.245 ± 1.969	0.592 ± 0.052
Black	6.666 ± 1.668	12.935 ± 1.777	5.658 ± 0.668	10.386 ± 1.395	0.577 ± 0.052
Yellow	6.074 ± 1.195	15.140 ± 1.948	5.898 ± 0.802	12.749 ± 1.495	0.584 ± 0.060

Table 5.37. High Handicap, 7iron, Back-foot Action Force Values (Mean ± SE).

The results identified the front-foot ground action forces were consistently higher when compared to the back-foot.

Tables 5.38 and 5.39 show front and back-foot Fz Maximum Time values (seconds) for each club, shoe and handicap condition.

	Shoe	**Driver** (Mean ± SE)	**3iron** (Mean ± SE)	**7iron** (Mean ± SE)
Low Handicap	Blue	2.700 ± 0.233	2.729 ± 0.271	2.626 ± 0.248
	Green	2.514 ± 0.268	2.773 ±0.119	2.425 ± 0.197
	Red	2.517 ± 0.123	2.751 ± 0.251	2.607 ± 0.185
	Black	2.745 ± 0.260	2.575 ± 0.201	2.462 ± 0.260
	Yellow	2.635 ± 0.237	2.551 ± 0.272	2.573 ± 0.148
Medium Handicap	Blue	2.326 ± 0.121	2.097 ± 0.107	2.152 ± 0.157
	Green	2.358 ± 0.127	2.179 ± 0.133	1.983 ± 0.125
	Red	2.348 ± 0.117	1.990 ± 0.098	2.045 ± 0.125
	Black	2.212 ± 0.171	2.408 ± 0.115	2.267 ± 0.159
	Yellow	2.197 ± 0.141	2.381 ± 0.270	2.199 ± 0.113
High Handicap	Blue	1.984 ± 0.223	1.803 ± 0.180	2.004 ± 0.230
	Green	1.768 ± 0.257	2.004 ± 0.236	1.996 ± 0.215
	Red	2.017 ± 0.253	1.880 ± 0.197	2.059 ± 0.150
	Black	2.056 ± 0.227	2.210 ± 0.186	2.086 ± 0.210
	Yellow	2.099 ± 0.253	2.339 ± 0.231	2.047 ± 0.266

Table 5.38. Mean Front-foot (left) Fz Maximum Time (seconds).

	Shoe	**Driver** (Mean ± SE)	**3iron** (Mean ± SE)	**7iron** (Mean ± SE)
Low Handicap	Blue	1.997 ± 0.141	1.970 ±0.235	1.885 ± 0.242
	Green	1.832 ± 0.167	2.009 ± 0.193	1.668 ± 0.173
	Red	1.812 ± 0.131	2.119 ± 0.234	1.834 ± 0.116
	Black	2.048 ± 0.218	1.847 ± 0.250	1.719 ± 0.171
	Yellow	1.928 ± 0.162	1.786 ± 0.261	1.792 ± 0.144
Medium Handicap	Blue	1.833 ± 0.103	1.716 ± 0.127	1.563 ± 0.065
	Green	1.888 ± 0.135	1.798 ± 0.100	1.463 ± 0.132
	Red	1.871 ± 0.145	1.516 ±0.152	1.527 ± 0.094
	Black	1.722 ± 0.128	1.956 ± 0.137	1.723 ± 0.238
	Yellow	1.703 ± 0.089	1.934 ± 0.270	1.679 ± 0.137
High Handicap	Blue	1.534 ± 0.159	1.446 ± 0.172	1.479 ± 0.216
	Green	1.335 ± 0.208	1.644 ± 0.238	1.458 ± 0.209
	Red	1.601 ± 0.193	1.419 ± 0.186	1.559 ± 0.187
	Black	1.658 ± 0.224	1.785 ± 0.115	1.524 ± 0.223
	Yellow	1.626 ± 0.229	1.906 ± 0.228	1.485 ± 0.312

Table 5.39. Mean Back-foot (right) Fz Maximum Time (seconds).

Tables 5.40 and 5.41 show front and back-foot Mz Maximum Time values (seconds) for each club, shoe and handicap condition.

	Shoe	Driver (Mean ± SE)	3iron (Mean ± SE)	7iron (Mean ± SE)
Low Handicap	Blue	1.732 ± 0.091	1.798 ± 0.243	1.692 ± 0.099
	Green	1.793 ± 0.075	2.058 ± 0.294	1.558 ± 0.075
	Red	1.761 ± 0.095	2.191 ± 0.235	1.803 ± 0.089
	Black	1.759 ± 0.071	1.716 ± 0.289	1.537 ± 0.080
	Yellow	1.771 ± 0.087	1.865 ± 0.347	2.099 ±0.107
Medium Handicap	Blue	1.742 ± 0.186	1.657 ± 0.211	1.820 ± 0.061
	Green	1.788 ± 0.020	1.678 ± 0.202	1.610 ± 0.081
	Red	1.774 ± 0.057	1.641 ± 0.151	1.684 ± 0.055
	Black	1.721 ± 0.079	1.697 ± 0.153	1.282 ± 0.075
	Yellow	1.736 ± 0.167	1.728 ± 0.328	1.645 ± 0.114
High Handicap	Blue	1.640 ± 0.109	1.457 ± 0.156	1.646 ± 0.076
	Green	1.760 ± 0.073	1.404 ± 0.200	1.685 ± 0.057
	Red	1.669 ± 0.105	1.315 ± 0.209	1.639 ± 0.084
	Black	1.681 ± 0.130	1.426 ± 0.176	1.363 ± 0.071
	Yellow	1.633 ± 0.083	1.543 ± 0.164	1.449 ± 0.088

Table 5.40. Mean Front-foot (left) Mz Maximum Time (seconds).

	Shoe	Driver (Mean ± SE)	3iron (Mean ± SE)	7iron (Mean ± SE)
Low Handicap	Blue	2.303 ± 0.164	2.146 ± 0.245	2.113 ± 0.213
	Green	2.191 ± 0.148	2.133 ± 0.186	1.975 ± 0.218
	Red	2.197 ± 0.207	2.371 ± 0.198	2.100 ± 0.220
	Black	2.298 ± 0.232	2.051 ± 0.250	1.746 ± 0.329
	Yellow	2.366 ± 0.216	2.082 ± 0.324	2.304 ± 0.228
Medium Handicap	Blue	2.147 ± 0.107	1.760 ± 0.106	1.905 ± 0.159
	Green	2.163 ± 0.104	1.966 ± 0.130	1.805 ± 0.105
	Red	2.073 ± 0.099	1.806 ± 0.105	1.737 ± 0.133
	Black	1.963 ± 0.142	1.797 ± 0.116	1.795 ± 0.395
	Yellow	1.899 ± 0.121	1.764 ± 0.214	1.927 ± 0.180
High Handicap	Blue	1.710 ± 0.205	1.548 ± 0.202	1.648 ± 0.185
	Green	1.689 ± 0.238	1.484 ± 0.243	1.749 ± 0.158
	Red	1.613 ±0.184	1.549 ± 0.141	1.582 ± 0.156
	Black	1.731 ± 0.214	1.764 ± 0.135	1.729 ± 0.153
	Yellow	1.638 ± 0.227	1.860 ± 0.199	1.651 ± 0.205

Table 5.41. Mean Back-foot (right) Mz Maximum Time (seconds).

Table 5.42 shows weight transfer times (seconds) within each club, shoe and handicap condition.

	Shoe	Driver (Mean ± SE)	3iron (Mean ± SE)	7iron (Mean ± SE)
Low Handicap	Blue	0.703 ± 0.092	0.759 ± 0.037	0.741 ± 0.006
	Green	0.682 ± 0.101	0.764 ± 0.074	0.757 ± 0.024
	Red	0.705 ± 0.009	0.632 ± 0.017	0.773 ± 0.069
	Black	0.697 ± 0.042	0.728 ± 0.049	0.743 ± 0.088
	Yellow	0.707 ± 0.075	0.766 ± 0.012	0.781 ± 0.004
Medium Handicap	Blue	0.493 ± 0.018	0.381 ± 0.020	0.589 ± 0.092
	Green	0.470 ± 0.009	0.381 ± 0.033	0.520 ± 0.007
	Red	0.477 ± 0.028	0.474 ± 0.054	0.518 ± 0.031
	Black	0.490 ± 0.043	0.452 ± 0.023	0.544 ± 0.079
	Yellow	0.493 ± 0.052	0.446 ± 0.001	0.520 ± 0.024
High Handicap	Blue	0.450 ± 0.065	0.357 ± 0.008	0.525 ± 0.014
	Green	0.433 ± 0.049	0.361 ± 0.002	0.537 ± 0.006
	Red	0.416 ± 0.060	0.461 ± 0.012	0.500 ± 0.037
	Black	0.398 ± 0.003	0.424 ± 0.071	0.562 ± 0.013
	Yellow	0.474 ± 0.024	0.433 ± 0.003	0.562 ± 0.045

Table 5.42. Mean Weight Transfer Times (seconds).

Slower weight transfer times can be seen within the low handicapped group when compared to the lower ability medium and high handicap groups.

5.6.5. Comparison of Action Force Results

5.6.5.1 *Comparison of Handicap Groups:*

The shoe-handicap interaction was subjected to a two-way ANOVA with repeated measures at 5% level to identify if any significant differences occurred within variables tested within the study. Mauchly's Test of Sphericity identified that the variance of differences between conditions were not significantly different, as a result a Greenhouse-Geisser adjustment was not required. Significant differences ($P<0.05$) were then detected by Post Hoc Tukey HSD tests. Raw ground action force data can be seen in appendix D.

Statistically significant ($P < 0.05$) main effects were identified within the following conditions:

Variable	Club Condition	Shoe Condition	Handicap Group Significant Differences (Mean ± SE)
Front-foot Fy Range	Driver (P = <.05)	Blue	- Low (0.26 ± 0.01) High (0.34 ± 0.02)
		Red	- Medium (0.28 ± 0.02) High (0.33 ± 0.02)

Table 5.43. Significant Handicap Differences.

(Note; Low = 0-7, Medium = 8-14 and High 15+)

No handicap group was identified as producing consistent differences between club and shoe conditions. Consequently there was support for three individual handicap groups to be amalgamated if more suitable in the consideration of the research results.

5.6.5.2: *Comparison of low, medium and high handicap groups in five different golf shoe sole interface shoe designs.*

Results are presented as mean and standard errors. Statistically significant ($P < 0.05$) main effects were identified for the torque and free moment rotational friction within the following conditions: Significant main effects ($F(4,80) = 14.34$, P= <.05) were identified within the back-foot Driver Tz range results between the Green (15.98 ± 1.11) shoe and the Blue (12.77 ± .83) and the Green and Black (12.73 ± .85) shoe conditions. No significant shoe handicap interactions were identified ($P = 1.00$) within the Tz range variable.

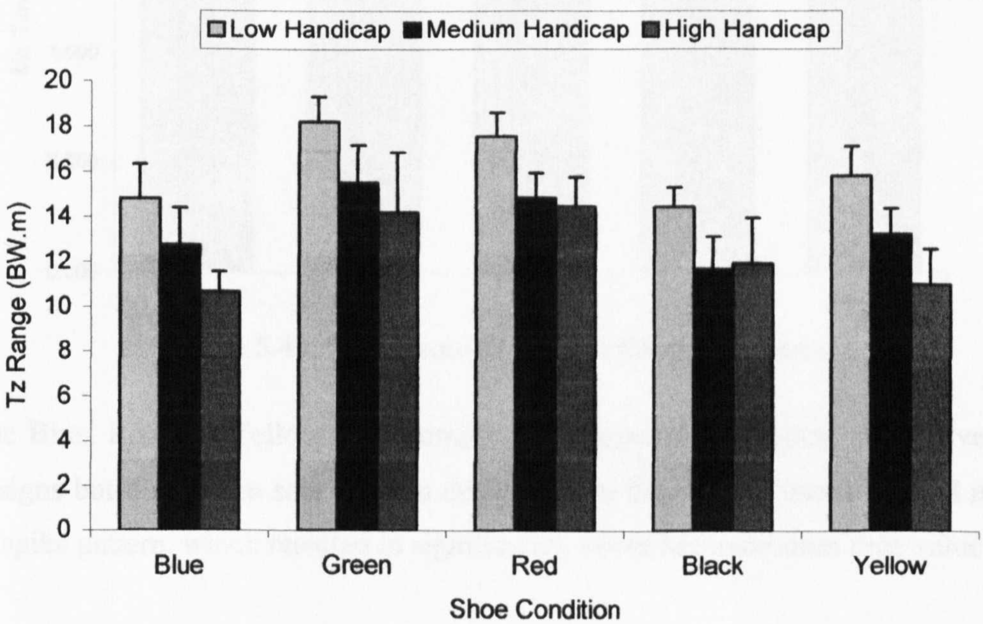


Figure 5.39. Driver Back-foot Tz Range (N.m).

	Shoe	Driver Tz Range (Mean ± SE)
Combined Handicap Groups	Blue*	12.77 ± 0.83
	Green*/**	15.98 ± 1.11
	Red	15.63 ± 0.69
	Black**	12.73 ± 0.85
	Yellow	13.35 ± 0.84

Table 5.44. Combined Handicap Driver Tz Range Back-foot Results (N.m).

* / ** Denotes where the Significant Differences Occurred.

Significant 7iron front-foot Mz maximum time differences $F(4,80) = .165$, $P = <.05$ were identified between the following shoe conditions. For all handicap groups together mean Black shoe results (1.39 ± .02) were significantly different to Blue (1.72 ± .03) Red (1.71 ± .03) and Yellow (1.72 ± .04) shoe conditions.

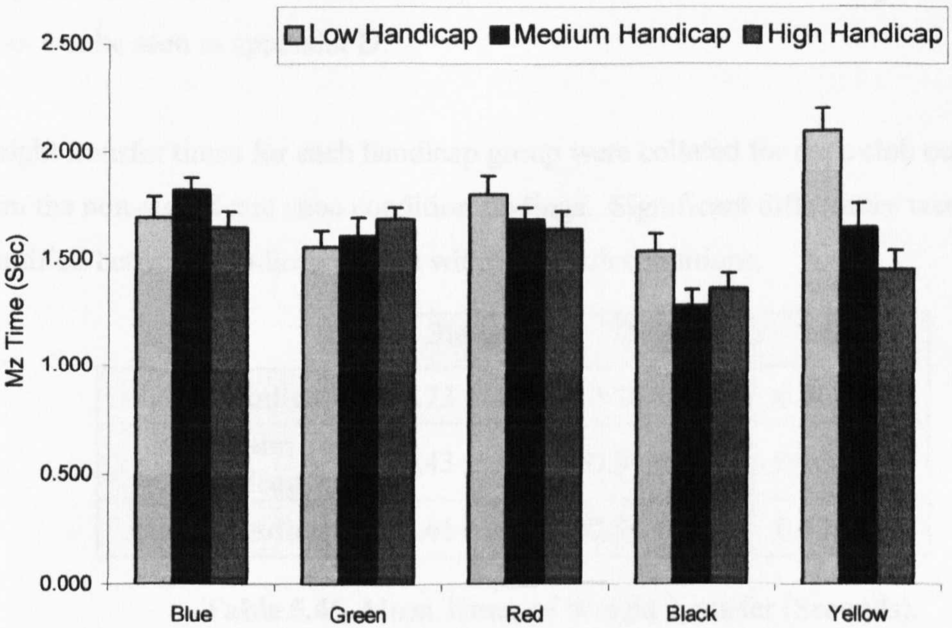


Figure 5.40. 7iron Front-foot, Mz Maximum Time (s).

The Blue, Red and Yellow shoe conditions incorporated the same alternative spike designs but differed in sole traction designs. The Black shoe condition had no sole or spike pattern, which resulted in significantly lower Mz maximum time value.

The Green shoe (1.62 ± .02) which incorporated the traditional metal spike were not identified to be significantly different to any other condition, but resulted in a faster time to Mz maximum (BW) when compared to the alternative spiked shoes.

	Shoe	7iron Mz max time (s) (Mean ± SE)
Combined Handicap Groups	Blue	1.719 ± 0.026
	Green	1.618 ± 0.023
	Red	1.709 ± 0.025
	Black	1.394 ± 0.024
	Yellow	1.715 ± 0.039

Table 5.45. Significant Combined Handicap Group 7iron Front-foot Results.

No significant shoe handicap interactions were identified within the Mz maximum time variable ($P = .349$).

5.6.5.3: *Comparison of Weight Transfer Times*

Weight transfer times from back-foot to front-foot were identified for each shoe, handicap and club condition. The results identified no significant differences in weight transfer times between handicap and shoe conditions. Raw weight transfer times can be seen in appendix D.

Weight transfer times for each handicap group were collated for each club condition from the non-significant shoe condition findings. Significant differences were identified between handicap groups within all club conditions.

	3iron	7iron	Driver
Low Handicap	0.73 ± .03	0.76 ± .01	0.70 ± .01
Medium Handicap	0.43 ± .02	0.54 ± .01	0.48 ± .01
High Handicap	0.41 ± .02	0.54 ± .01	0.43 ± .01

Table 5.46. Mean Times of Weight Transfer (Seconds).

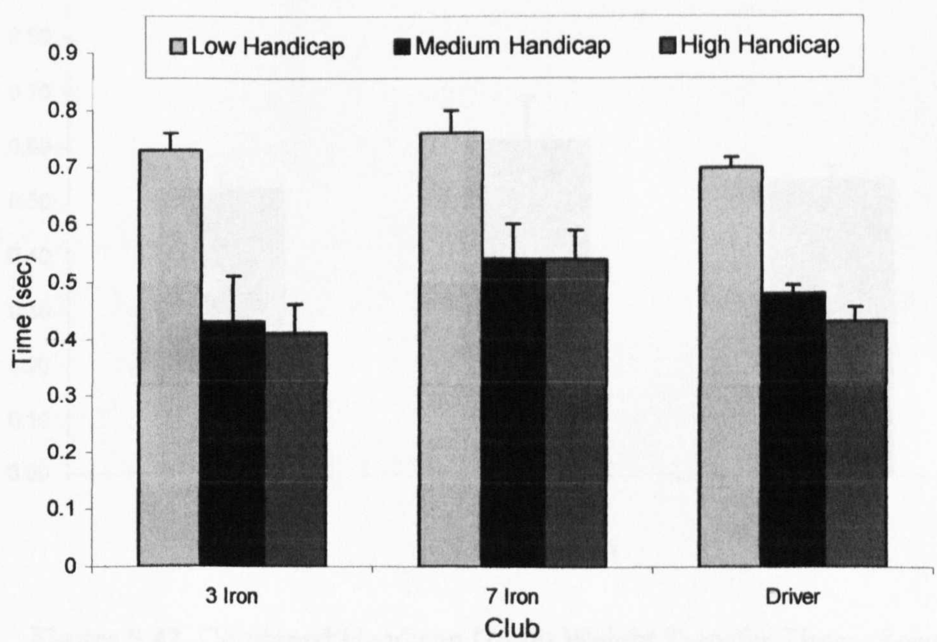


Figure 5.41. Comparison of Mean Weight Transfer Times within Handicap Groups with Different Clubs.

During the golf swing the low handicap players produced the slowest weight transfer times. Significant differences were identified within the 3iron results F(2,8) = 55.72,

$P = <.05$. The low handicap group (.73 ± .03) were identified to produce significantly slower weight transfer times to the medium handicapped players (.43 ± .02) and the high handicapped group (.41 ± .02). Significant differences were identified within the7iron results $F(2,8) = 101.01$, $P = <.05$. The low handicap group (.76 ± .01) were identified to produce significantly slower weight transfer times to the medium handicapped players (.54 ± .01) and the high handicapped group (.54 ± .01).

Significant differences were also identified within the Driver club condition $F(2,8) = 165.36$, $P = <.05$. The low handicap group (.70 ± .01) were identified to produce significantly slower weight transfer times to the medium handicapped players (.48 ± .01) and the high handicapped group (.43 ± .01).

The slower transfer of body weight from the back to the front-foot identified within the low handicapped players may account for more consistent swing performance, as the players are able to better control the forces created at the feet throughout the swing.

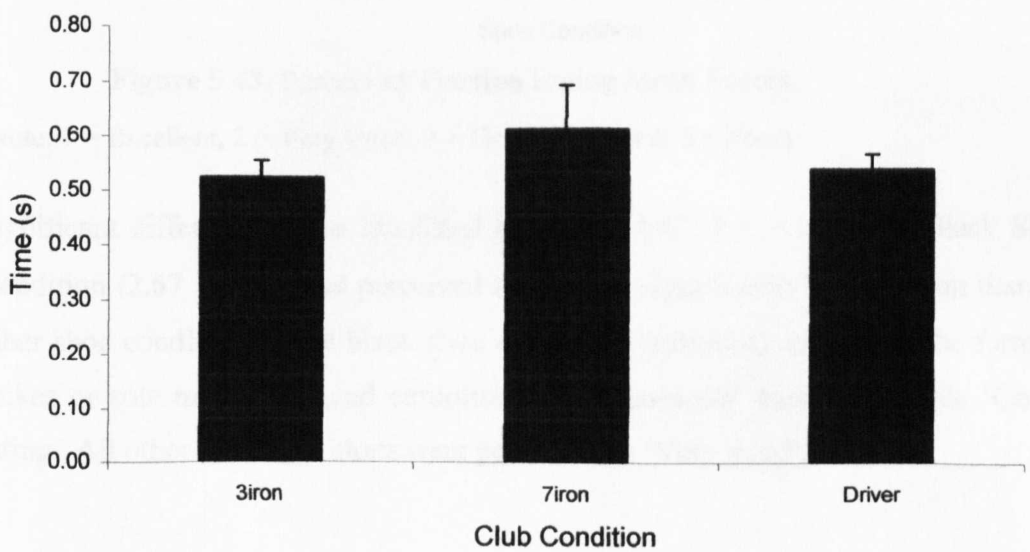


Figure 5.42. Combined Handicap Group Weight Transfer Times (Seconds) Between Club Conditions.

The 7iron (.61 ± .01) was identified to produce significantly slower weight transfer times when compared to the driver (.54 ± .01) and 3iron (.52 ± .01) club conditions $F(2,8) = 1.26$, $P = <.05$).

5.6.6: Perception Rating Scale Results:

Each golfer provided a number of perceptual ratings for each of the five shoe conditions. The handicap group perception scores were combined for each shoe condition. The total mean values were subjected to a one-way repeated ANOVA ($P < 0.05$). A Post Hoc Tukey Test identified where the significant differences occurred. Raw perception data can be seen in appendix E.

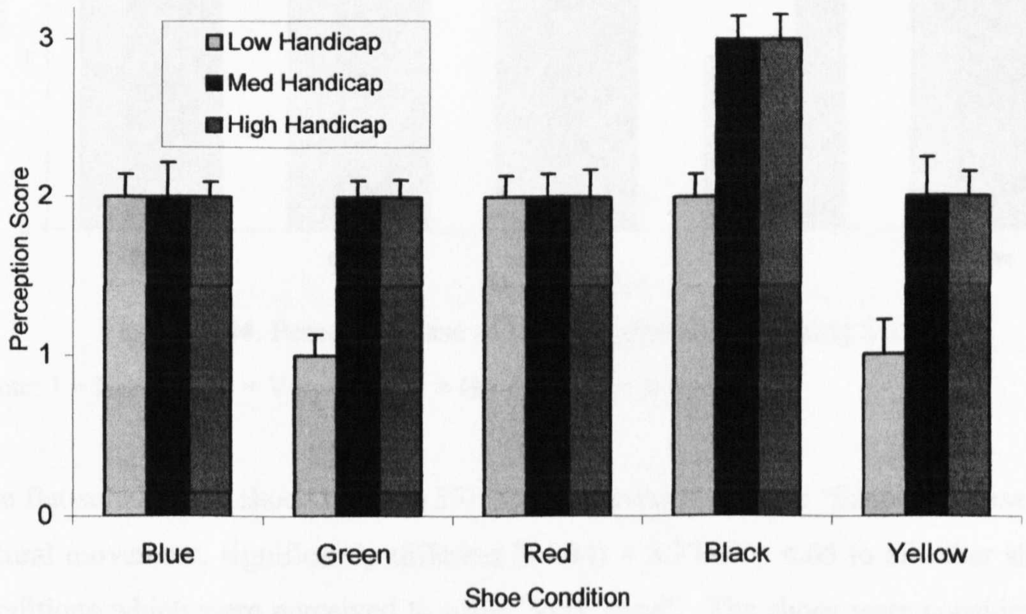


Figure 5.43. Perceived Traction Rating Mean Scores.
(Note: 1 = Excellent, 2 = Very Good, 3 = Good, 4 = Fair & 5 = Poor)

Significant differences were identified $F(4,84) = 4.47$, $P = <.05$. The Black Shoe Condition (2.67 ± 0.45) was perceived to produce significantly less traction than all other shoe conditions. The black shoe offered no additional traction in the form of spikes or sole mouldings, and conformed to the subjects' perception scale 'Good' rating. All other shoe conditions were perceived as 'Very good'.

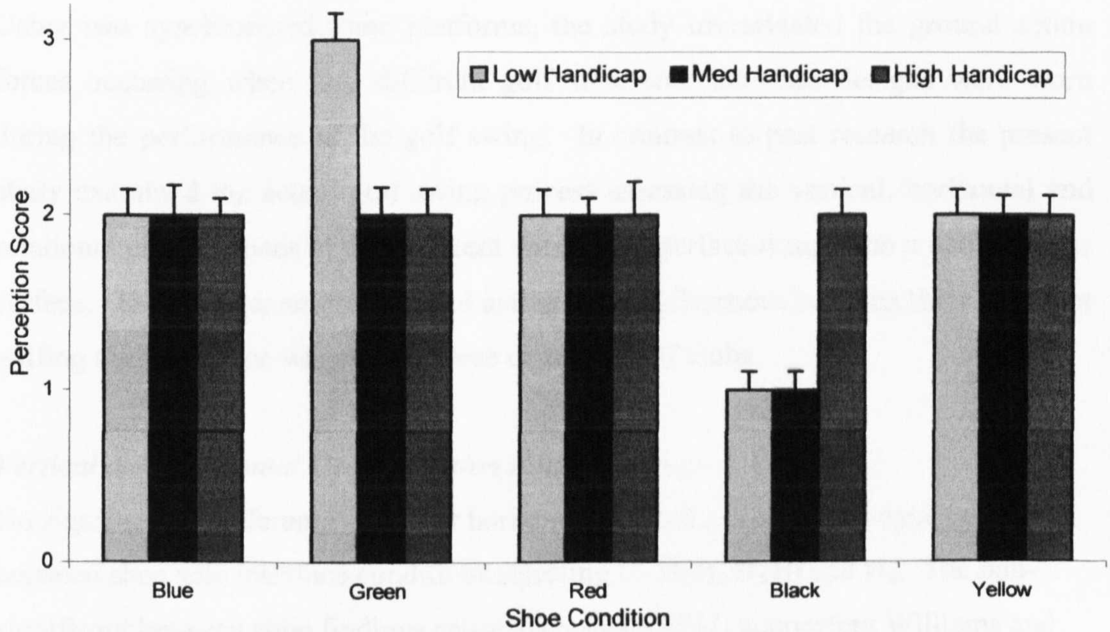


Figure 5.44. Perceived Ease of Natural Movement, Rating Scores.
(Note: 1 = Excellent, 2 = Very Good, 3 = Good, 4 = Fair & 5 = Poor)

The flat-soled Black shoe (1.33 ± 0.37) was perceived to provide 'Excellent' ease of natural movement, significantly different $F(4,84) = 5.77$, $P = <.05$ to all other shoe conditions which were perceived to offer 'Very good'. The shoes were considered similar in terms of ankle and foot support with no significant differences were identified for 'Perceived Ankle and Foot Support' ($P = .794$).

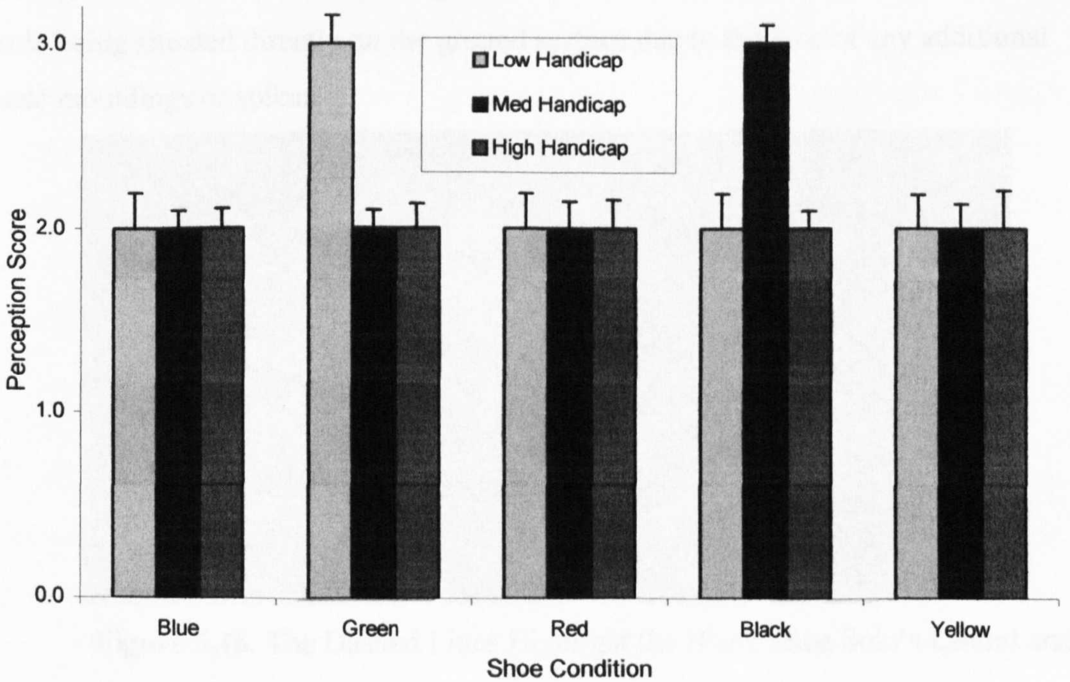


Figure 5.45. Perceived Ankle and Foot Support Mean Rating Scores.

5.7: DISCUSSION

Using two synchronised force platforms, the study investigated the ground action forces occurring when five different golf shoe sole interface designs were worn during the performance of the golf swing. In contrast to past research the present study examined the actual golf swing process assessing the vertical, horizontal and rotational performances of the different shoe sole interface designs on a natural grass surface. The study examined ground action force differences between three different golfing ability groups when using three different golf clubs.

Vertical and Horizontal Ground Action Force Findings:

No significantly different vertical or horizontal ground action forces were evident between shoe sole interface conditions rejecting H_1 H_2 H_3 H_4 H_5 and H_6. The non-significant between shoe findings cause acceptance of H_0 supporting Williams and Sih's (1998) research, which also did not identify any significant differences between traditional and alternative spikes when evaluated on artificial surface. In addition to Williams and Sih's study a flat-soled sole interface was assessed within the present study. The non-significant findings raise concerns with the four golf shoe sole traction designs tested, as they were unable to offer the golfers any additional vertical or horizontal traction during the golf swing process when compared to the flat-soled shoe. It is probable that the flat-soled Black shoe utilised its sole and heel edges acting as a form of traction (see figure 5.46). This traction was created by the shoe sole being situated directly on the ground surface due to the lack of any additional sole mouldings or spikes.

Figure 5.46. The Dashed Lines Highlight the Black Shoe Sole's Lateral and Heel Edge Borders.

Front Versus Back-foot Vertical and Horizontal Findings:

The results identified distinct differences within the vertical and horizontal ground action values between the front-foot and back-foot. The front shoe sole interfaces were subjected to greater forces within all handicap and club conditions. The latter was not hypothesized, but clear differences were identified supporting the observations of Calsoo, (1967), Williams and Cavanagh, (1983), Konig and Tamres (1992), and Thomas and Pietrocarlo, (1996).

The vertical and horizontal demands placed on the back-foot during the swing, were relatively minor, when compared to the front-foot. They consisted of the ability to work as a couple with the front-foot. During the backswing the back-foot generated an anterior to posterior force coupled with the front-foot pushing in the posterior to anterior direction creating a clockwise rotation of the body and club.
The back shoe was also required to support a medial to lateral body weight shift to the top of the backswing. Subsequently larger back-foot posterior to anterior forces coupled with the front-foot's anterior to posterior forces are created producing a fast anticlockwise downswing rotation of the upper body and club. At the point of ball impact and throughout the follow-through the front-foot was required to support the golfer's momentum travelling from the medial to lateral edge of the shoe.
Pforringer, and Rosemeyer (1989), describe this stage of the swing process as a very labile equilibrium, i.e., an insecure stance with a simultaneous, limited, mechanical shifting of the foot and of the force from the medial to the lateral edge. Pforringer, and Rosemeyer (1989) further suggested it is possible that this mechanical limitation is due to golf shoes' being incorrectly designed for such a medial to lateral tilting motion. In conclusion the front-foot shoe must be designed to support and decelerate the rapid anticlockwise rotations of the golfer and club while both shoes must work as a couple to create and control the clock / anticlockwise rotations.

Rotational Ground Action Force Findings:

The traditional spiked Green shoe produced a significantly greater Tz range within the back-foot when compared to the alternatively spiked Blue and flat-soled Black shoe conditions when using a driver accepting H_7 and H_8. The Tz range incorporated the rotational torques of both the backswing and downswing movements during the swing process. The results highlighted the tractional properties of the traditional spiked shoe sole during rotational movements. The shoe's greater Tz range within the backswing enabled the golfer to rotate around the foot/leg creating a coiled position with reduced possibility of the shoe slipping under the clockwise force. This pivot point placed the golfer in a stable position for the accelerated transition into the downswing. The shoe's sole bed incorporated lateral sole mouldings and longer metal spikes (see figure 5.47), which opposed the rotational torques produced with the driver during the swing process.

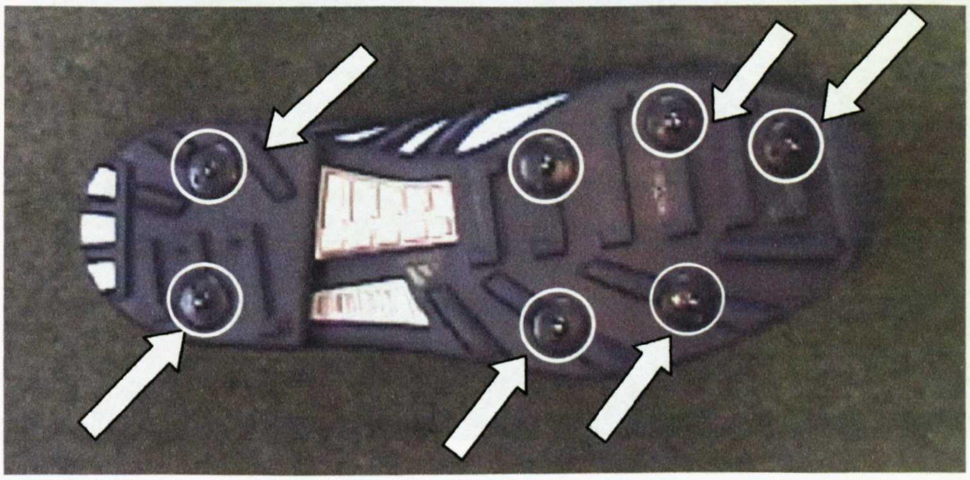


Figure 5.47. Arrows Identifying Sole Bed Traction Opposing the Clockwise and Anticlockwise Rotations within the Green Shoe. Circles Identify the Traditional Metal Spike Placements.

Conversely during the anticlockwise rotation of the downswing and follow through the back-foot is required rotate anticlockwise around the fixed medial forefoot of the shoe allowing the golfers bodyweight to transfer onto and rotate around the fixed front-foot / leg. The back-foot must facilitate this weight transfer and body rotation whilst enabling the golfer to maintain stability during the follow through allowing a natural rotational movement of the body through the swing.

The findings suggest the positioning of the soles traction bars in conjunction with longer traditional spikes are proficient at resisting the rotational torques during the backswing when compared to the other shoe sole conditions tested. However, such traction during the follow-through does not facilitate the natural movements of the golfer during the latter stages of the swing. Further alterations to the soles traction placements are required to gain a functional sole bed that facilitates and opposes the forces created during the asymmetrical swing process.

In contrast to the traditional spiked Green shoe the alternatively spiked Blue sole and flat-soled Black shoe provided significantly smaller Tz range values and would not offer the same support during the backswing required for the golfer to rotate around. However, the limited traction within the forefoot would enhance the anticlockwise rotation aiding the golfers body rotation.

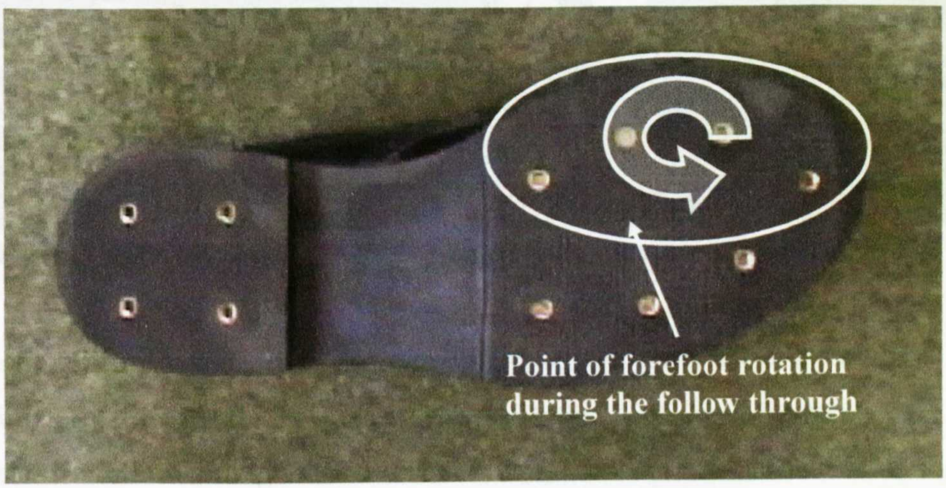


Figure 5.48. Black Shoe Sole Identifying the Point of Forefoot Rotation During the Follow-through Stages of the Swing.

The alternatively spiked Blue shoe sole incorporated small sole mouldings (approximately 10mm long) and had only six alternative spikes in comparison to seven spikes on the other spiked shoe soles resulting in the smaller Tz range values (see figure 5.49).

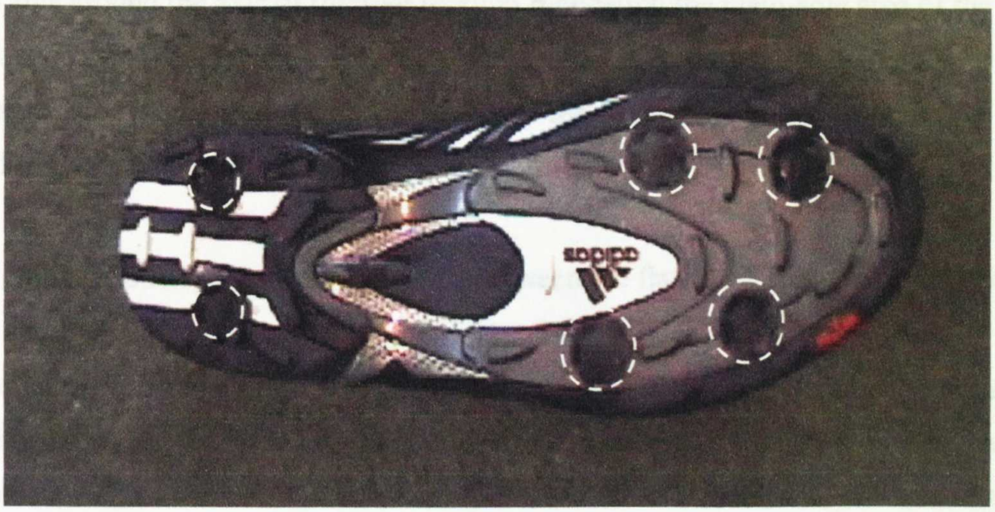


Figure 5.49. Blue Shoe Sole Incorporated Six Alternative Spikes (circled).

The traction incorporated within the rear Blue shoe sole is not suitable for maintaining rotational stability during the backswing but allowed the rotational anticlockwise follow-through movements. It would be expected that the Blue shoe sole would provide limited front-foot traction during the rotational stages of the swing process. This was not however identified suggesting that when greater forces are applied to the shoe (as identified within the front-foot during the later stages of the swing) the sole can provide comparable traction to the other shoes tested.

The non-significant differences identified within the alternatively spiked Red and Yellow shoes highlight the shoes' ability to function comparably to the traditional spiked Green shoe, which produced the highest ground action forces. However the shoes also provided comparable Tz range values to the Blue alternatively spiked and flat-soled shoes, which provided the lowest ground action forces. The findings highlight the close similarity between the different shoe sole interfaces tested.

It is evident that the desired traction requirements of the back-foot shoe sole are dependent on the stage of the swing process. The back-foot requirements during the clockwise backswing are to support the golfers rotation acting as a pivot point, while in the anticlockwise downswing and follow through the back-foot needs to rotate unrestricted. The opposing requirements through the swing process make the sole and spike design increasingly difficult. An asymmetrical back shoe sole design needs to incorporate the shoes differing requirements, as at present golf shoe sole designs do not incorporate these golfing requirements. A shoe incorporating a plainsoled area around the axis of forefoot rotation replicating the plain-sole area of the Black shoe sole would enable the natural forefoot rotation during the swing. In contrast a shoe incorporating traction similar to the Green shoe sole to support the foot during the backswing is also required.

No significant differences were identified between the flat-soled Black shoe and the three alternatively spiked shoes accepting H_0. The findings highlight concerns regarding the tractional properties of the alternatively spiked shoes during rotational movements within the back-foot. Through subsequent analysis of the recorded foot movements it was identified that traction gained from the flat-soled shoe was a result of the lower sole contact with the ground and the shoe embedding the lateral and medial sole edge into the grass surface. This was enhanced during the driver club condition due to the increase in rotational torques.

Significant main effects were identified for the7iron Front-foot, Mz Maximum Time. The flat-soled Black shoe was identified to produce faster Mz maximum times when compared to the alternatively spiked Blue, Red and Yellow shoes. Front-foot Mz rotational traction is vital during the swing, with the emphasis of force produced during the follow-through. It is at this point when the club momentum and the body weight transfer onto the front shoe and the club begins to decelerate around the axis of the golfer's front leg. High positive Mz rotation was also identified during the downswing stage of the swing prior to ball impact. This increase in Mz force is a result of the golfer initiating a powerful anticlockwise downward club movement from the Fy couple.

The faster Mz maximum time found in the Black shoe condition increases the probability of slipping during the swing. The results highlight the tractional limitations of the Black flat-soled shoe condition, as it produced the fastest time to the maximum Mz force accepting H_7. The alternatively spiked shoes offered more grip resulting in longer force generation until the shoe slips under the force or the swing momentum slows before any slipping occurs.

The alternatively spiked Yellow, Red and Blue shoes provided comparable traction. The shoe conditions incorporated either lateral edge sole mouldings (See figures 5.50 and 5.51) or large traction bars (see figure 5.52). These mouldings restricted any rotational torques during the swing process increasing the time to Mz maximum force.

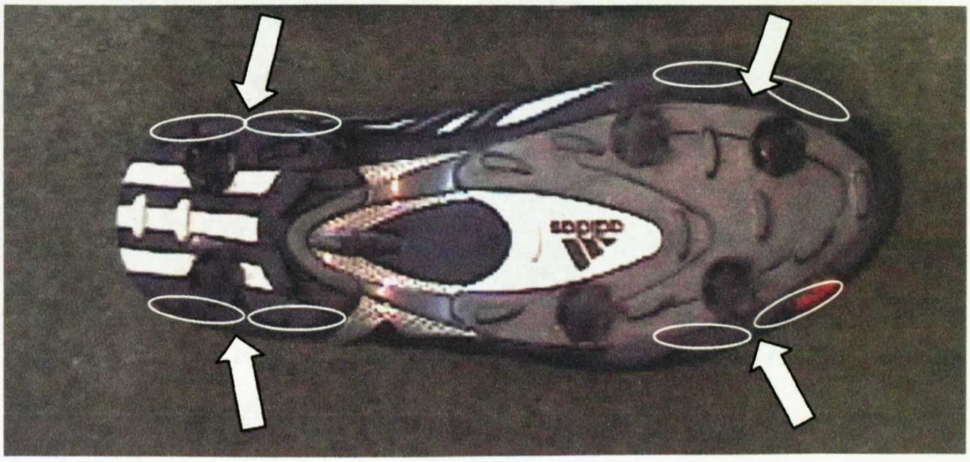


Figure 5.50. Ovals Identify the Lateral Edge Sole Mouldings Upon The Blue Alternativly Spiked Shoe. The Arrows Identify Example Applied Rotational Force Directions During the Swing Process.

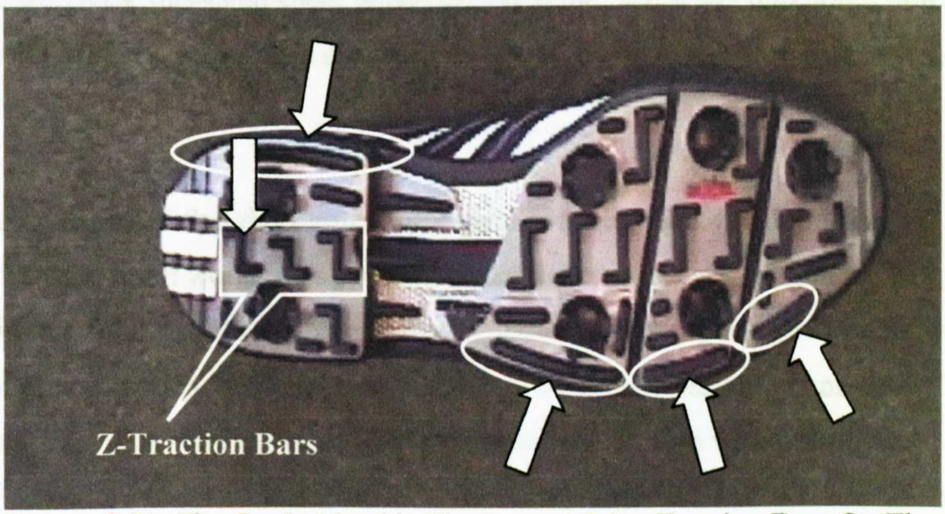


Figure 5.51. The Ovals Identify The Lateral Edge Traction Bars On The Yellow Shoe Sole. The Rectangle Highlights The Z-Traction Mouldings. The Arrows Represent Example Directions of Rotational Force.

The Yellow shoe had fewer lateral edge mouldings but the sole protrusions were longer. The sole also incorporated 'Z' shaped mouldings, which also opposed the rotational torques (see figure 5.51).

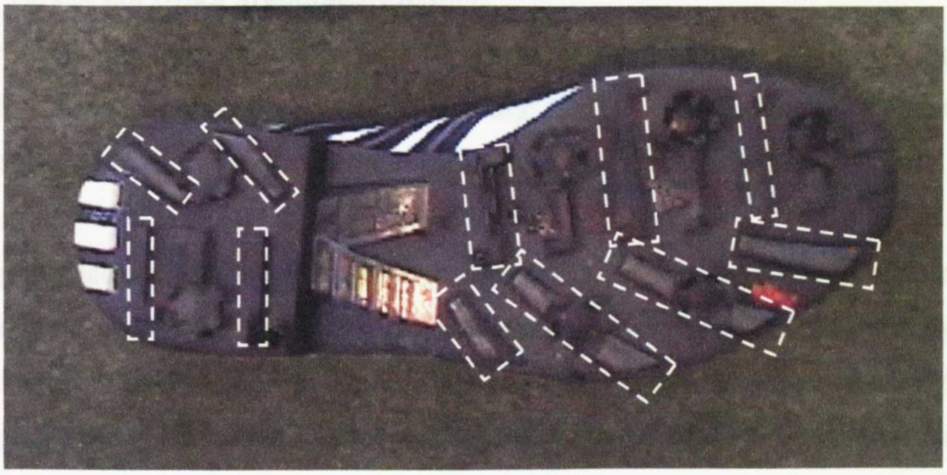


Figure 5.52. The Red Shoe Sole Incorperated Large Sole Traction Bar Mouldings (highlighted)

The traditional spiked Green shoes' non-significant results highlight the shoes ability to function comparably to the alternatively spiked shoes, which produced the longest time to Mz maximum. However the shoes also provided comparable Mz maximum times to the Black flat-soled shoe, which provided the fastest Mz maximum time. The findings highlight the close similarity between the different shoe sole interfaces tested.

It would be expected that the significantly quicker time to Mz max found in the Black shoe condition would result in significant differences occurring in COFxy, due to the limited friction. This was not however identified. It is possible that this was a result of only rotational friction being measured within this variable as no linear frictional properties were measured, no significant differences were identified.

No other between-shoe significant rotational differences were identified within the rotational variables causing acceptance of H_0. The non-significant results support the concerns highlighted within the vertical and horizontal findings, with traditional and alternatively spiked golf shoes only providing comparable sole traction to the flat-soled shoe condition. As mentioned previously within the vertical and horizontal discussion the Black shoe sole generated its rotational traction through the sole edge and borders making direct contact with the grass surface.

Front Versus Back-foot Rotational Findings:

Higher rotational torques were identified within the front-foot when compared to the back-foot supporting the vertical and horizontal findings. As previously stated the differences were not hypothesized but clear differences were identified.

During the backswing the golfers body weight transfers onto the back-foot. During this stage the golfer and club rotate clockwise around the fixed axis of the back-foot until the top of the backswing. During this stage the front-foot maintains a stable position for the golfer to maintain stability. From the top of the backswing down through ball impact both the front and back feet produce anticlockwise rotational torques in collaboration with the vertical and horizontal forces to generate the fast anticlockwise swing. Following ball impact the highest rotational torques during the swing were applied to the front shoe to control and decelerate the club and body rotations. It is at this stage when the shoe must maintain a stable foot placement to decelerate the swing momentum. During this stage minimal rotational forces are applied to the back-foot as it rotates onto the medial forefoot allowing the club and body to rotate around the axis of the front-foot.

As identified within the vertical and horizontal back-foot findings the role of the back-foot is dependent on the stage of the swing process. During the backswing the golfer places the whole shoe sole bed on the ground and rotates around it, resulting in the need for high sole traction. However during the downswing as the golfers weight is transferred onto the front-foot the back-foot starts to rotate on the medial forefoot and limited traction is required. Assessing the shoe with force platforms does not identify which locations of the shoe are in contact with the ground surface. The present study visually assessed the shoe positioning using video feedback, however to gain a detailed understanding of the shoe ground contact areas in-shoe analysis is required. In-shoe assessment would distinguish the function of the back-foot heel region during the clockwise and anticlockwise movements. It is this sole region that could allow the shoe to function as required throughout the swing. If in-shoe analysis identifies limited heel contact during this stage it would be possible to design a back-foot shoe sole bed that has high heel and lateral forefoot traction but minimal forefoot medial traction. Such a design would maintain traction during the backswing when the heel is in contact with the ground but facilitate the forefoot rotations during the follow through when the heel is lifted from the ground.

Handicap Group Findings:

A two-way ANOVA with repeated measures was used to test if any significant ground action force differences occurred between handicaps. Only one significant handicap differences was identified within the ground action force variables. No handicap group was identified as producing consistently significant results between club and shoe conditions rejecting H_1 and supporting H_O.

The non-significant and unrelated significant findings within the handicap group comparisons suggest rejection of the claims by Koenig and Tamres (1992) that a person with a higher handicap should have a different shoe design than a better player. The results identified that an apparently perfect sequencing of forces at the feet might occur during a swing where the golfer misses the ball, as found by Williams and Cavanagh, (1983). This was supported by Worsfold *et al.*, (2002) research which identified poorer golfers were often unable to utilise the forces generated at the feet, while it is the better players were able to consistently transform these forces into longer and more accurate shots. Variability was higher in the high handicap group as identified within the shot outcome results however the nature of differences did not follow a pattern, which emphasises golf play.

Weight Transfer Time Findings:

Weight transfer time from the back-foot to the front-foot was identified to be significantly slower within the 7iron club condition. No measurements of club head speeds were made, but it was observed that the golfers used the longer 3iron and driver to accelerate through the ball at a much faster speed than when using the shorter 7iron club (used for shorter shots). It should also be noted that although not significant in both the back-foot and front-foot the Driver Fz maximum action forces were lower than for the 3 and7iron. This is a result of the different club rotation identified when using the longest club (the driver). The change in swing pattern is a result of the increased length of the club (see figures 5.57 and 5.58), resulting in a wider swing with the club swung more around the body as opposed to up and over the body as with the shorter irons. The more vertical swing pattern identified within the irons cause the higher Fz action forces as they pull down on the golfer.

The golfers weight transfer times within the present study identified that the low handicap players transferred their body weight from the back-foot during the backswing onto the front-foot during the downswing and follow through at a slower rate than that of the medium and high handicap golfers. The results offer an insight into the processes involved for a constantly successful shot. A slower more controlled transfer of weight from the back-foot to the front allowed greater control of the forces created at the feet throughout the swing resulting in less error at ball impact. In comparison, the faster weight transfer found within the less able players suggested the players were moving their weight rapidly causing uncontrolled or less repeatable ball contacts. Although weight transfer times are related to golfing technique rather than a direct determinate of the shoe design (as highlighted in the non significant findings between shoe conditions); an improvement in shoe design may facilitate a more natural and supportive base to aid the golf population as a whole.

The identification of significant difference in weight transfer time between the low handicapped golfers and the higher handicapped players in all club conditions has large implications regarding improvements in swing performance and coaching. Due to the faster swing played by the higher handicapped players; it is possible that they would require greater shoe traction to control these forces compared to the low handicapped players. However few significant differences were identified between the forces produced at the shoe sole interface between the handicap groups. The results further emphasise a limitation in the control of the swing process by the higher handicapped players rather than a greater force production. The findings reject Koenig and Tamres (1992) recommendations for different shoe designs for differing handicaps. Subsequently correctly designed single golf shoe sole interface design would serve for all golfing abilities.

Shot Outcome Findings:

From the shot outcome data sheet it was identified that the lower handicap players shots were more consistent (89% straight) and that the high handicap group were far more erratic and unpredictable (54% miss hit). It can be suggested that at present modern golf shoes offer the same performance characteristics to players across all abilities and that it is not the generation of forces at the feet that ultimately determine golfing ability, but how these forces are utilised into performing a consistently accurate shot.

Club Condition Findings:

Ground action forces were higher within the driver club condition when compared to the 3 and 7irons within all the linear and rotational variables measured with exception to the vertical Fz forces supporting H_1. The higher forces were a result of the driver's longer shaft length and larger club head.

The lower vertical forces identified within the driver club condition when compared to the 3 and 7irons across all handicap groups are a result of the differing swing planes of the clubs. The swing plane is changed as a result of the club shaft length. The longer club shaft within the driver causes a wider more horizontal swing as opposed to the shorter irons, which are swung in a more vertical plane. The shorter irons were swung more 'up and over' the golfer (See figure 5.53) resulting in higher vertical forces while the driver was swung more 'up and around' the golfer (See figure 5.54) resulting in higher rotational, medial lateral and anterior posterior ground action forces.

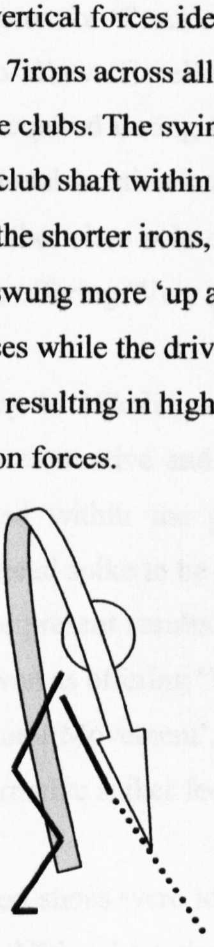


Figure 5.53. Example Iron Swing-Plane.

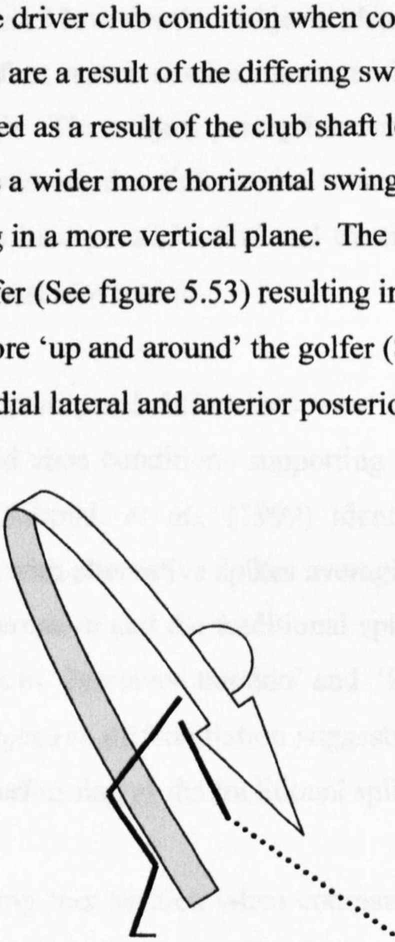


Figure 5.54. Example Driver Swing-Plane.

Perception Score Findings:

A five-point perception rating scale similar to that used by Nikolai, *et al.,* (1999) was used in the present study to identify a subjective scores for each condition. The subjective 'Perceived Traction' revealed the Black shoe condition to be perceived differently to all other shoe conditions. Subjects ranked the condition as rate 'Good' on perception scale. All other shoe conditions were perceived as 'Very good'. Subjects stated that a reduction in traction was noticeable during the later stages of the swing within the front-foot, i.e. through the fast downswing and during the decelerating of the club around the front-foot. It must be noted that the shoe offered no traction other than the EVA sole bed itself but was still identified as rating 'Good' on the rating scale. It would be expected that this condition would be seen to offer the lowest perception rating of traction.

The Black shoe condition was also identified to be significantly different to all other shoe conditions for 'Perceived Ease of Natural Movement'. Subjects identified the condition to allow 'Excellent' natural rear foot anticlockwise movement onto the medial toe required during the follow-through. The subject perception was a result of no additional traction on allowing an unrestricted anticlockwise rotation of the foot. The other shoe sole conditions, which incorporated additional traction, were perceived as offering 'Very good' ease of natural movement.

Contradictory to Nikolai, *et al.,* (1999) no perceptual differences were identified between the alternative and traditional spiked shoe conditions supporting the force data obtained within the present study. Nikolai, *et al.,* (1999) identified the traditional metal spike to be seen as excellent with alternative spikes averaging 'Fair' ratings. The present results identified all alternative and the traditional spiked shoe to be perceived as offering 'Very good' scores in 'Perceived traction' and 'Perceived Ease of Natural Movement'. The lack of subjective differentiation suggests that the modern alternative spikes feel as if they are performing as the traditional spike does.

The flat-soled shoes were identified as offering less traction when compared to the shoes with additional traction, contradicting the kinetic results. The findings support the mixed findings recognized in many running shoe perception scale research. When used to rank running shoe properties, it has been identified that subjects are able to perceive selective differences (Jorden and Bartlett, 1994) but unable to distinguish between others (Shorten and Winslow, 1992). The use of perceptual data in relation to kinetic and kinematic data provided an additional dimension to the results, one that may be useful in shoe design on order to gain a better understanding of how the golfers identify with the shoes during the golfing action. The validity of such observations must be questioned when comparing to scientific analysis, due to the continued contradictions in results.

It must be observed that that the shoe needs to be designed to function with the human foot during the golf swing, offering the necessary support, traction and allow for the natural foot movements during the swing and a perceptual evaluation of its performance may yield information that the mechanical testing may not. It may be beneficial to shoe producers and players alike to try to identify why at present golfers are unable to identify specific movements within their feet. This limitation in sensory feedback may limit the golfers ability to produce the most effective movements or create the appropriate support required for an improved shot. At present it is unclear if golf shoes restrict the necessary feedback from the foot / shoe combination or due to the complexity and speed of the movement in that many golfers are unaware of their foot movements and are focusing on other movements within the swing cycle. Further research will increase understanding in the area.

The perceptual analysis used in the present study could be questioned as all shoe conditions incorporated the same uppers with the exception of the Black shoe. This visual difference may have influenced the subjective ratings to some degree. Unfortunately it was not possible to match the uppers of this shoe condition with the others tested. It was unclear whether the appearance or brand affected the subject's judgment. Future research may eliminate any appearance-based judgments through matching all shoe uppers.

The subjective scoring used in the present study also only used a five-point scale rating from excellent to poor. It may be questioned that this scale limited the judgment of the golfers; as a result a more subjective ten or fifteen point scale may be appropriate. Research may look at possible links to the limited perceptual abilities of golfers and the corresponding foot movements that occur.

Design changes in golf shoes are not likely to change a golfer's game dramatically, but may provide a helpful edge on performance and thereby permit more intensive concentration on the movements of the upper extremities, the spinal column, and the hips. A properly designed shoe will make a difference, but it is currently difficult to quantify. If a golfer perceives the shoe as helping to play more consistent better shots, and feels more natural, there would be a positive psychological effect. With psychology playing an important role in golf performance, the golf shoe could therefore improve golfing performance.

Limitations within the Current Testing Modality:

The shoes and spike designs tested were all produced by the same manufacture, with the exception of the flat-soled shoe; as a result it was not possible to compare between different manufacture's designs. Future testing of different sole and spike designs would allow a greater understanding of the differences between alternative spike and sole manufactures.

Although the force platforms were covered with natural grass it was not viable to grass around the plates to look like a flat-grassed area highlighting the force platforms. Although golfers became accustomed to the environment, a natural grassed area would look more realistic to the golfers, and restore ecological validity.

The present study incorporated grass that allowed the surface to be penetrated by the spikes and added traction but did not allow the subjects weight to sink into the turf. Further shoe tests on extreme wet and dry conditions would develop a wider understanding of the shoe's performance characteristics. Further analysis of shoe performance on ground angle (e.g. up/down hill or right/left slant) will also allow further evaluation of conditions in which the golf shoe is required to perform.

Wallace *et al*, (1994) identified a major drawbacks to the limited past research in incorporating the application of laboratory-based findings to the actual game of golf. The artificial operating environment of the indoor golf station may affect the performance of the golfer, and the outcome of the shot is unknown. Williams and Sih, (1998) further stated that more tests are needed using a natural grass surface and conditions where slip is more likely to occur to further define any effect alternative-spike outsole designs may have on golf swing dynamics. The present studie's methodology has created a test environment that has eliminated these problems within past research, allowing a detailed comparison and evaluation of current golf shoe functions and design.

5.8. Conclusion

Ground action force analysis of the golf shoe sole interfaces during the golf swing process provided an understanding of the dynamic shoe-ground interaction. The results identified no differences between the shoe sole interface designs within the vertical / horizontal and limited differences within the rotational ground action force variables. The results raise concerns regarding the limited tractional performance of the traditional and alternatively spiked shoes when subjected to dynamic golf swing forces on a natural grass surface. The results identified both the traditional and alternative spiked golf shoe interfaces' to perform comparably to a flat-soled shoe in all of the linear and all but two rotational variables. Consequently the traditional and alternative spiked shoes tested did not consistently provide the golfer with any additional functional benefits during the swing process. The dynamic testing modality used within the present study highlighted large contradictions between the present findings and those identified within the previous mechanical traction testing device analysis (chapter 4). The different results suggest it is not possible to accurately test shoe sole interfaces through a mechanical testing device and relate them to a dynamic movement. Only through actual dynamic sports specific movements can an accurate understanding of the performance characteristic of sports shoes be gained.

Forces applied to the front shoe sole interfaces were identified to be greater in all ground action force conditions suggesting the need for an asymmetrical front and back shoe sole design. A front-foot sole design incorporating mouldings, spikes and projections specifically positioned to oppose the large vertical / horizontal and rotational forces is required. In contrast a back shoe sole is required to maintain whole foot stability during the backswing but facilitates the rotational moments during the follow through.

Differences in forces produced at the feet during the swing phase were found not to be significantly different between handicap groups. The results suggest a universal shoe design may be used across golfing abilities. A significant difference in the time of weight transfer from back to front-foot during the downswing was however identified. The low handicapped players produced significantly slower weight transfer times when compared to the less able golfers. Although the findings do not have any implication on shoe design due to the non-significant ground action force findings, the results do have an impact on the understanding of golf technique and coaching the golf swing.

From the present study it was possible to identify the forces that occurred between the shoe sole and ground surface. The results gave information of the shoes performance with the ground surface. It is however unclear how the shoe interacts with the golfers foot during the swing. A study by Wallace *et al,* (1994) was one of the first studies to identify the forces that occurred within the shoe through pressure insoles inserted into the shoes. Pressure patterns identified the locations on the sole where forces were greatest, allowing design features on the outsole to be localised and devised in relation to the applied forces. The results from the present study alongside further research using shoe insoles will enable a detailed evaluation of the dynamic shoe / foot / ground interaction on natural surface.

CHAPTER 6: IN-SHOE PLANTAR PRESSURE MEASUREMENTS OF DIFFERENT GOLF SHOE SOLE DESIGNS

6.1: INTRODUCTION

Besides gravitation and air resistance, the external forces acting on the human body act on the plantar surface of the foot and generate movement according to Newton's laws (De Roy, 2002). The forces and torques produced between the ground and shoes have been researched in golf predominantly through using force platforms measuring ground action forces. These measures have been assessed both in mechanical and dynamic studies within chapters four and five. Chapter five identified few differences between shoe sole conditions during the actual swing process in contrast to the mechanical testing detailed within chapter four. The variations in shoe sole performance between testing modalities emphasised the need for the shoes to be tested dynamically during actual golfing performance to gain a valid golf shoe sole assessment. The previous ground action force studies identified the forces, torques and interactions between the whole shoe sole interface and the ground surface. To further assess the functional properties of the shoe interfaces a more sensitive assessment of specific shoe sole regions is required, which could be potentially achieved through actual in-shoe pressure measurements. Investigation into the interaction between the golfer and shoe-sole interface will identify specific in-shoe regions of pressure transferred to the shoe sole by the golfers feet. Subsequently it should be possible to accurately identify functional aspects of the shoe sole interface's tested and sole regions that require further support / traction through additional traction placement. Hennig (1998) identifies the importance of such measurements stating that 'Because footwear modifies the foot to ground interaction considerably, in-shoe pressure measurements are of special interest'. Further McPoil *et al.*, (1995) stated that in-shoe pressure measurements can provide a greater understanding of the effects of specialised footwear, as well as assist in their modification to maximise their benefit to the user. Pressure is defined as the force divided by the area on which the force acts and is measured in kPa (100 kPa = 10 N/cm^2) (Hennig, 1998). Traditional plantar pressure assessments of the feet have previously been evaluated using pressure mats placed between the bare-foot or shoe and the floor. However, such systems fail to provide information about pressures occurring within the shoe (McPoil *et al.*, 1995). In-shoe plantar pressure insole systems have the potential for recording data during consecutive steps / movements without imposing any constraints on foot placement (Cordero *et al.*, 2004). De Roy, (2002) stated foot pressure measurement is of utmost importance in understanding the central role of biomechanical issues in the design, manufacture, and assessment of insoles and footwear. In-shoe pressure insoles (shown in figure 6.1) are measuring devices that record the pressure distribution under the foot sole.

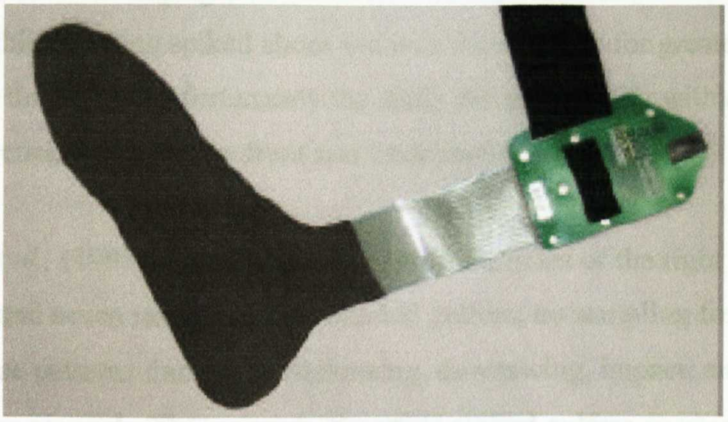


Figure 6.1. An Example In-shoe Plantar Pressure Insole.

Few studies have been conducted on the forces produced between the shoe and foot during the golf swing, despite belief in the importance of forces and weight placed and transferred at the feet during the swing process (Kawashimia *et al,* 1998). One golf study by Pforringer and Rosemeyer (1989) analysed the motion of the feet using a pressure sensitive plate. Although no values were reported, the study described the different pressures associated with the forces at the two feet during the swing process. The study identified the demands placed on the back-foot are relatively minor when compared to the front-foot during a golf swing. The study allowed an understanding of the basic pressures being produced at the feet. However as previously stated it is not possible to assess the pressures occurring within the shoe when using pressure mats. It is not possible to directly relate the studies findings with actual pressures produced during a typical swing, as the golfers played shots barefoot creating uncharacteristic movements and thus force and pressure generation to the natural swing movement.

A more detailed in-shoe study by Wallace *et al.*, (1994) identified foot pressures and movements of the body and club during the golf swing. Special consideration was given to the load-bearing roles of the feet. Six right-handed male golfers wore spiked and spike-less shoes and played shots of a grass-covered tee-box. Each shoe contained eight piezo-electric film transducers operating at 400 Hz for a period of 10 seconds. The study reported that subjects were able to generate up to twice the peak pressures during the downswing within the spiked shoes when compared to the spike-less shoe condition. Wallace *et al.*, (1994) found high peak pressures at the first metatarsal heads immediately prior to ball impact. The results highlighted the inertial effects of the swinging club (driver), with the observation of the greater magnitudes while wearing spiked shoes indicate the capacity for greater force generation by the body. Unfortunately the study did not identify within the results specific differences between the front and back shoe conditions.

Kawashima *et al.*, (1998) placed load-cells under the soles of the right and left feet of seven skilled and seven unskilled right handed golfers; no sampling frequencies were reported. Force patterns during the backswing, downswing, impact, and follow-through were measured. The research identified skilled golfers exerted forces on the central area of the right foot sole during the backswing then transferred it onto the inner edge of the left foot sole in the downswing. At impact, forces were exerted on the left foot. Unskilled golfers tended to meet impact with force on their right foot, and there was a tendency for the weight to remain there during the follow-through. The study was limited to only measuring three specific areas of each foot, the digitus minimus area, hallux area and the calcaneous area. The large in-shoe areas assessed allowed only the general pressure patterns at the feet during the swing to be distinguished. Such general regional analysis limited the understanding of the complex foot movements during the swing. It was not clear what golfing ability the 'unskilled' group had or even if they had played prior to testing. As a result it is not possible to identify if the differences in pressures are related to a golfing population or to golfers and non-golfers.

Although not golf specific, Coyles and Lake (1999) researched in-shoe pressure measurements to determine the applicability of the technique in the detection of differences between commercially available football boot designs. Eight male subjects wore three football boots with different stud dimensions and configurations, each of which contained a developmental pressure insole (RSscan international, Belgium) with a sampling frequency of 500Hz. Subjects were requested to run on a motorised treadmill and on natural turf at a speed of 4.5 m/s. The study identified no significant differences in peak pressure or load rate between the three boot designs. Although the study was unable to differentiate between the test boots, the study did emphasis the individual nature of plantar pressure distribution and the need to consider all factors of outsole design and not simply stud location. It is possible that the non-significant findings were a result of similarity between sole designs and outsole plate stiffness which was sufficient to distribute the pressure across the forefoot, so reducing potential localised pressure under the studs of the boot. Coyles and Lake stated that when assessing pressure distribution, 'trials should be undertaken on the appropriate surface to ensure distribution patterns are reflective'. Brizuela *el al.*, (1999) investigated plantar pressures within five football boot prototypes during running on a natural surface. The football boots varied in the number and location of the stud placements. A single insole situated within the right boot incorporated 64 piezoelectric sensors and a sampling frequency of 100Hz was used. The analysis identified that the distribution and number of studs had a significant difference on the plantar pressures during running. The analysis of only one boot limited the understanding of how the boots functioned as a couple during the running analysis. It can also be questioned if testing football boot in-shoe pressures during linear running is specific to the demands placed on the shoe during actual football performance.

One of the main reasons for little in-shoe research is that several limitations have been associated with in-shoe pressure measurements (McPoil *et al.*, 1995). McPoil *et al*, stated that the sensor transducers within the insoles are subject to damage resulting from repeated or excessive loading in the same region. Although not quantified McPoil *et al.*, (1995) identified that the hot, humid, and often contoured environment within the shoe can also affect insole sensor performance. However Ahroni *et al* (1998) suggested conducting tests on the same day, or that using new insoles for each subject might reduce the variability identified within pressure insole analysis.

Within golf, the limited in-shoe studies conducted have only allowed in-shoe pressures to be measured at between three and eight locations on the foot during the swing. With so few sensors it is not possible to ascertain how the multi-jointed foot is actually functioning during the swing process. Many previous studies have not reported in-shoe pressure values making it hard to compare in-shoe studies and associate the findings with past ground reaction force research.

During the last decade in-shoe pressure measurement systems have evolved from a relatively large single sensor placed under the foot location of interest to eight or more individual sensors placed under anatomical landmarks on the plantar surface of the foot (De Roy, 2002). Technological developments have enabled recent commercially available systems to monitor hundreds of small pressure sensors distributed over the whole plantar surface of the foot, and thus eliminated the need for precise anatomical positioning. Although Coyles and Lake's research in 1999 used developmental insoles sampling at 500Hz most commercially available systems were only sampling around 100Hz at that time as used by Brizuela *el al.*, (1999). Higher sampling rates are now generally available, meaning that the registration system passes on information every 0.002 seconds, significantly improving insole pressure measurement accuracy (De Roy, 2002).

6.2: AIM

It is becoming apparent that the shoe can be an effective tool for manipulating human movement. McPoil *et al* (1995) suggest that with the wide range of shoe design possibilities, coupled with the body's tendency to adjust in predictable ways to shoe mechanical characteristics, a new way to manipulate human kinematics and kinetics has been identified, as well as a convenient model for studying biomechanical adaptation. With such interactions being identified between the shoe and human a detailed analysis of the shoe / golfer interaction is necessary to quantify shoe differences. The aim of the present study was to analyse in-shoe pressures to identify any within-plantar shoe pressure differences between shoe sole conditions. The study aimed to highlight any differences during the golf swing, which occurred either with the shoe at the foot-insole-interface or at the shoe-sole-grass interface. Such an investigation would aid in the understanding of adaptations to different shoe sole designs and the subsequent effect this might have in performance of the golf swing.

The study utilised an insole system sampling at 500Hz (higher than any past reported golfing study) on two natural grass covered force plates. Three modern golf shoes varying in spike pattern, design and sole design were tested.

Limitations have been identified (chapter 3, 4 and 5) with mechanical testing of the shoe-ground interaction when compared to dynamic analysis. Dynamic shoe-ground analysis identified significant differences between weight transfer times and shoe conditions within the Tz and Mz rotational ground action forces. It is not clear if these differences were a result of differences in the shoe-ground interaction or in-shoe alterations. When comparing pressure analysis and ground action forces it is important to recognise that in-shoe pressure systems only measure vertical forces and are unable to measure shear forces within the shoe. As the Mz rotational force incorporates shear forces it is not possible to relate the past chapters findings with the present in-shoe findings.

6.3: HYPOTHESES:

6.3.1: In-shoe Plantar Pressure Hypotheses:

H_0: No differences in in-shoe pressures will be identified between shoe conditions.

H_1: Traditional metal spiked golf shoes will produce higher in-shoe pressures when compared to a flat-soled golf shoe.

H_2: Alternative spiked golf shoes will produce higher in-shoe pressures when compared to a flat-soled golf shoe.

H_3: Traditional metal spiked shoes will produce higher in-shoe pressures when compared to alternative spiked shoes.

6.3.2: Rotational Ground Action Force Hypotheses:

H_0: No differences in rotational ground action forces will be identified between shoe conditions.

H_1: Traditional metal spiked golf shoes will produce higher rotational ground action forces when compared to a flat-soled golf shoe.

H_2: Alternative spiked golf shoes will produce higher rotational ground action forces when compared to a flat-soled golf shoe.

H_3: Traditional metal spiked shoes will produce higher rotational ground action forces when compared to alternative spiked shoes.

6.4: Method

Following ethical approval eighteen right-handed male (age 29 ± 2.16 years) (weight 81.36 ± 2.75 Kg) (height 179.94 ± 1.86 cm) golfers volunteered for the study. Handicaps were noted and golfers were divided into three groups with six subjects having a low handicap (0-7), six with a medium (8-14), and six with a high handicap (15+). The subjects all played three times or more a month, with the highest handicap being 19 and the lowest 0. Each subject provided written informed consent, and was reminded that they could withdraw from the study at any time without prejudice (Appendix F).

Although handicaps were noted within the present study, no significant ground action force differences were identified between handicap groups within chapter five. As a result the present study did not compare between golfing abilities yet aimed to provide a distribution of skill level, representative of club standard golfers who were likely to be using the types of shoe under test.

Three golf shoes were tested; shoe details are presented within chapter 3.1. Shoe conditions comprised of one metal spiked 'Green' (figure 3.1), one alternatively spiked shoe condition 'Yellow' (figure 3.4) and one flat-soled shoe 'Black' (figure 3.5). No consistent significant ground action force differences were identified between the three alternatively spiked shoes tested within chapter five. Consequently the present study focused on one alternatively spiked shoe condition due to the similarity in alternatively spiked shoe performance.

In-Shoe Pressure Insole Procedure:

Plantar pressure insoles (Footscan RSscan International, Belgium) with less than 2 hours use were used (Footscan, polymer sensors of size 7mm to 5mm). Pressure insoles were fitted inside both left and right shoes of the tested golf shoes. The shoe insole size was selected by the subject to fit comfortably within the shoe. Once fitted into the shoe the pressure insoles were connected to a Footscan data logger operating at 500Hz attached to the waist of the subjects. The insole data collection was triggered by a remote control and recorded for a period of 8 seconds. Subsequent analysis objectively selected the start and end of the swing process within the 8 seconds data collection. This selected information was used for statistical analysis.

Footscan pressure insole 2.33 system software (RSscan International, Belgium) running on an IBM compatible computer controlled the data sampling and recording of the data to hard disk for storage and subsequent analysis. Each subject's body weight was entered into the Footscan software enabling calibration of specific in-shoe pressures to the individual subject.

Markers were set by dynamic regional analysis, based on screening the foot from different directions and adapted to the foot type. The software automatically detected the footprint as a left or right foot. Markers were then placed on the footprint identifying the foot length and width. The footscan software then placed a mask on top of the footprint dividing it in nine regions proportional over foot length and width. Pressure data was then analyzed from the nine regions shown in figure 6.2 of both the left and right feet. Statistical analysis was performed on the subsequent results as described later in this chapter.

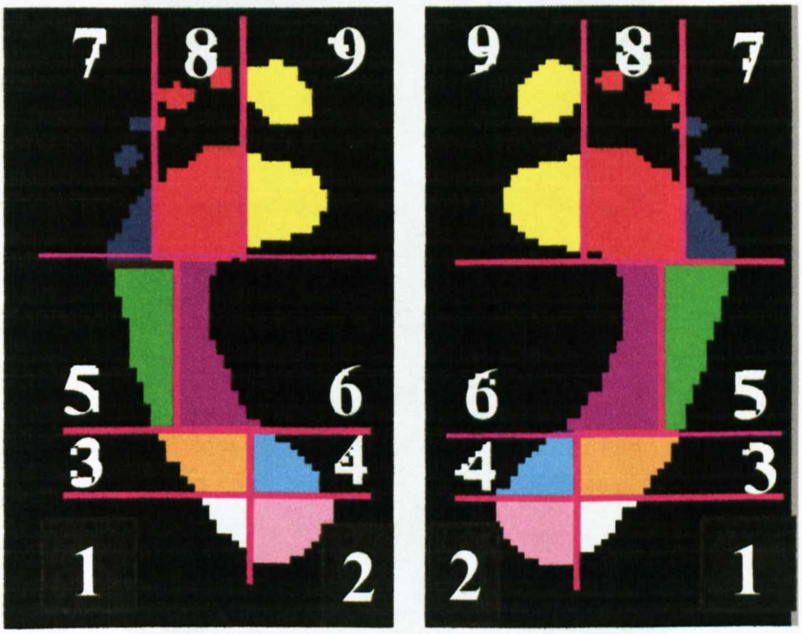


Figure 6.2. Example Dynamic Region Analysis Identifying the 9 Foot Regions of the Left (Front) and 9 Foot Regions of the Right (Back) Feet

Sixteen specific anatomical markers were then selected within the nine identified by the software; hallux (T_1), phalanges, T_2, T_3, T_4, T_5, metatarsal heads M_1, M_2, M_3, M_4, M_5, anterior mid-foot V_1, posterior mid-foot V_2, lateral anterior heel H_1, medial anterior heel H_2, lateral posterior heel H_3 and medial posterior heel H_4 (see figure 6.3).

These were selected only for in-shoe observational results throughout the swing and were not used for statistical purposes.

The insole system calculated the tightness of the shoelaces and the subject body weight was identified as a zero offset. Consequently the system calculated only dynamic pressure movements during the swing process, which were normalised for the golfers' body weight. If a golfer were to stand still or a static weight was placed on the insole the pressure sensors would read zero due to only static pressures being applied.

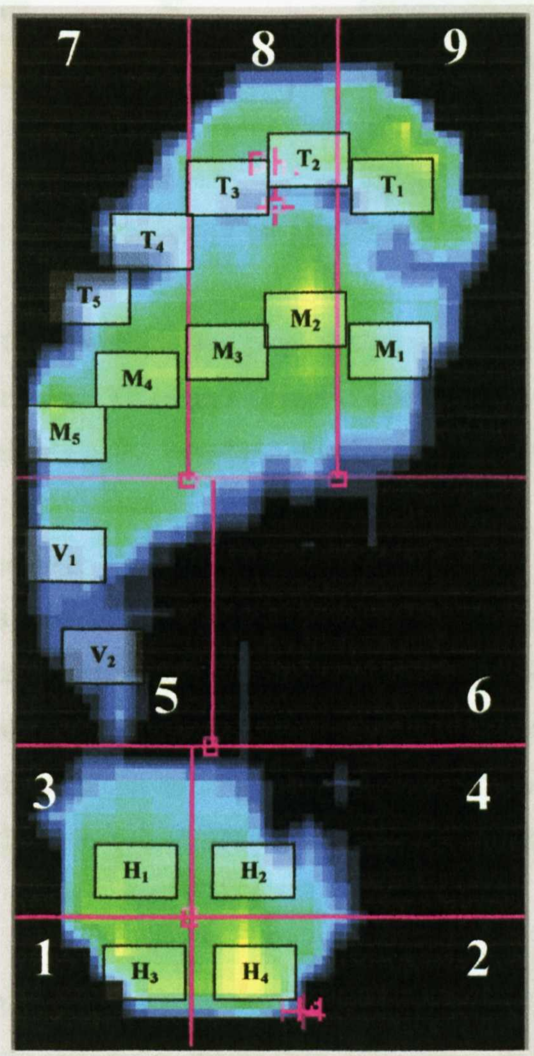


Figure 6.3: Dynamic Region Analysis (note: marker placements are only example placements).

Different colours represented different regional in-shoe pressures throughout the shoe sole (figure 6.4).

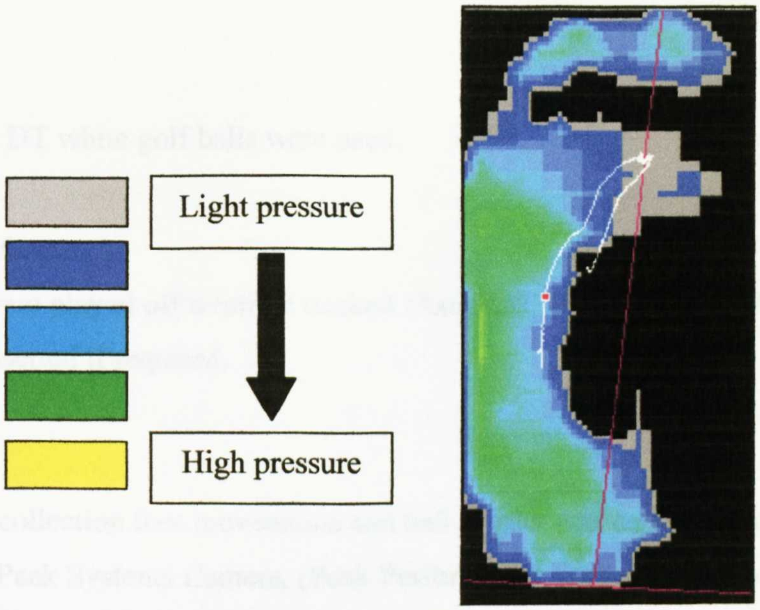


Figure 6.4. Pictorial Representation of the Different In-Shoe Pressure Colours.

Subjects were given time (walking and playing shots) to become accustomed to wearing the shoes / insoles. The data recorder connected to the insoles was located on the back of the golfer's waist in order not to interfere with the golfing movement.

Force Platform Procedure:

Ground action forces were simultaneously measured on two grass covered Kistler Force Platforms (Kistler instruments Ltd). The force platform system data acquisition was initiated using a remote trigger synchronised with the shoe insole system trigger. The force-plates were covered in a natural grass surface. The force platform and grass-plate set-up is described in the general methodology chapter 3.2.

Golf Equipment:

Clubs: Two different clubs were used by each subject in each shoe condition. The clubs were the subjects own clubs, which they were accustomed to. A driver, which incorporates the longest shaft with the largest head, and used for long powerful shots ranging on average between 200 – 285yards. A 7iron, which is shorter in shaft length, and used for medium to short approach shots to the hole with a range of between 100 – 180 yards was also used. The two club conditions were selected as they represent a short iron, which is swung in a more vertical plane and longer shafted driver, which is swung in a wider plane were selected due to the differences in their swing paths.

Balls:

New Titleist DT white golf balls were used.

Tee Mat Surface:

Golf shots were played off a rubber backed 'Astroturf' tee mat, which allowed tee pegs to be inserted if required.

Camera:

During data collection foot movements and ball impact was captured using a 200 Hz High Speed Peak Systems Camera, (Peak Performance Technologies inc. Englewood, Colorado USA). The test environment can be seen in figure 6.5.

Data Collection:

Five shots were played with each of the two clubs (i.e. 10 shots in each shoe) in each of the different shoe conditions. Club and shoe order was randomised for each participant.

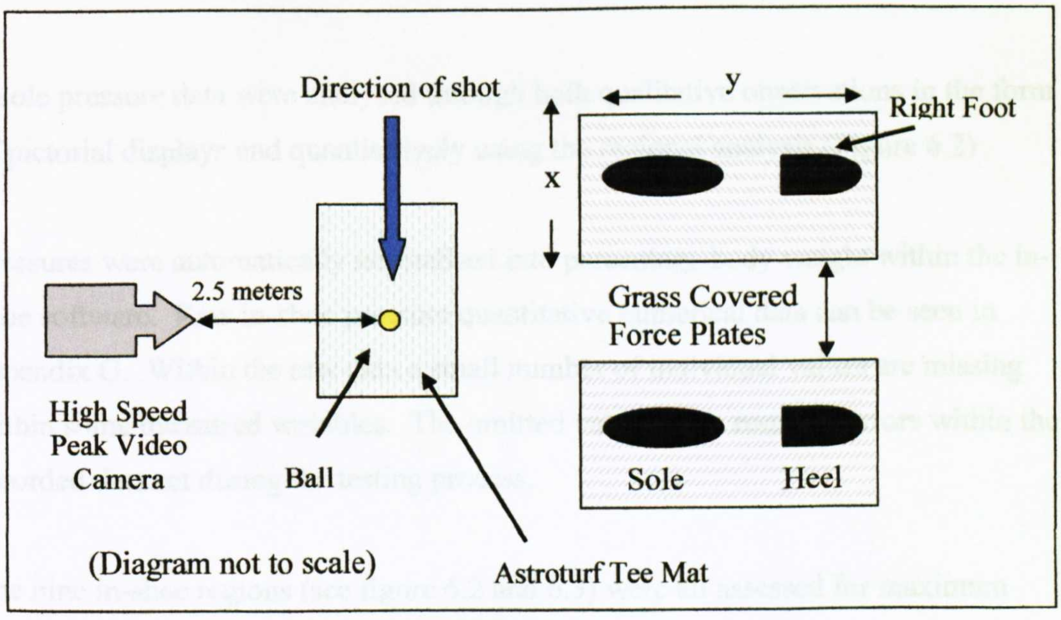


Figure 6.5. Test Environment for a Right-Handed Golfer.

A trigger from a small impact at the back of one of the force-plates prior to the start of each golf swing enabled the video and force platform systems to be synchronized.

The time of ball impact was determined by calculating the number of fields from a force plate signal to ball impact from the high-speed video footage to the nearest 0.005 second.

Data Analysis:

Within the study reported in chapter five higher rotational shoe-ground interaction torques (Tz ranges) were identified as a difference associated with shoe sole design at the back-foot with the driver. The variable Tz is a measure of the free moment about the centre of pressure. Table 6.1 shows the ground action force variables selected for analysis within this experimental study. Forces were normalised to percentage body weight for each participant in each condition and club selection to allow group comparisons.

Rotational Forces (N.m)	Maximum	Max Time	Range
Tz Back-foot Driver	√	√	√
Tz Back-foot 7iron	√	√	√
Tz Front-foot Driver	√	√	√
Tz Front-foot 7iron	√	√	√

Table 6.1. Variables Tested within the Study (√ tested)

Insole pressure data were analysed through both qualitative observations in the form of pictorial displays and quantitatively using the regional analysis (Figure 6.2)

Pressures were automatically normalised into percentage body weight within the in-shoe software. Raw in-shoe pressure quantitative numerical data can be seen in appendix G. Within the raw data a small number of individual values are missing within some measured variables. The omitted values are a result of errors within the recorded data set during the testing process.

The nine in-shoe regions (see figure 6.2 and 6.3) were all assessed for maximum pressure; average pressure over the swing process; and pressure at ball impact.

Mean, standard deviation and standard errors were calculated for all data. Sphericity was assessed using Mauchly's Test to identify if variance of differences between conditions were equal. If sphericity was not assumed, Greenhouse-Geisser corrections were used. Data was analysed using a two-way ANOVA with repeated measures (shoe / club) at a 5% significance level. Significant differences were detected by Post Hoc Tukey HSD tests set at a 5% level of significance.

6.5: RESULTS

In-Shoe Pressure Distribution Observations

Note: pressure diagrams show typical observed examples of the pressures occurring between the foot and shoe insole from a single trial using a 7iron. The left foot diagram is classified as the front-foot and the right foot diagram is classified as the back-foot.

Address

Back-foot and Front-foot

At address golfers distributed their weight evenly between their feet. Pressures were distributed over the predominant bony features with little to no pressure located around the medial arch of the feet.

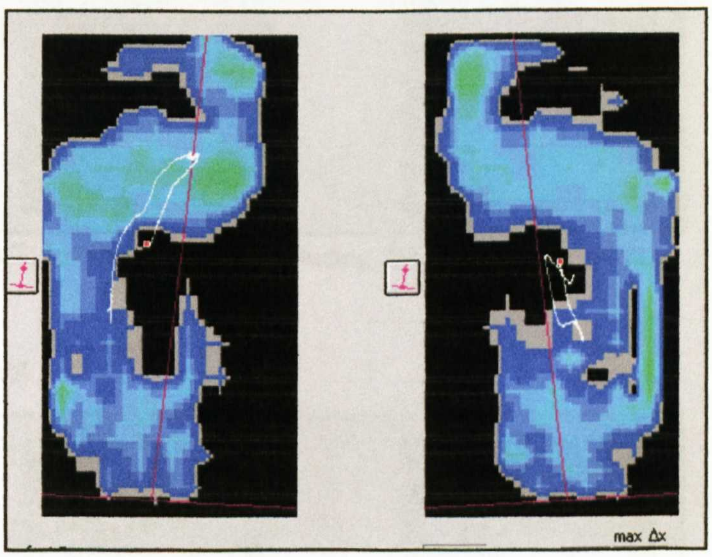


Figure 6.6. In-Shoe Pressures At Address (7iron).

Back-Swing

Back-foot

In-shoe pressure distributed from T_1, T_2, M_1 and M_2 laterally across M_1, M_2, M_3, M_4 and M_5. Pressure was identified throughout V_1, V_2, and the calcaneous (H_1, H_2, H_3, H_4). Pressure partially distributed back medially across; M_4, M_5, V_1, V_2, and $H_{1\text{-}4}$ at the top of the backswing as the club was positioned horizontally above the golfers shoulders. Pressures within the shoe increased to their highest at any stage of the swing as the golfer placed their bodyweight onto the back-foot, which they used to rotate clockwise around.

Front-foot

During the backswing the in-shoe pressures reduced, with the limited pressure being distributed upon T_1, T_2, M_1 and M_2. This is the least demanding stage of the swing for the front-foot as it is used primarily for balance as the golfer coils around the back-foot / leg. At the top of the back-swing pressure was limited throughout the shoe, with the only point of pressure at T_1, and M_1.

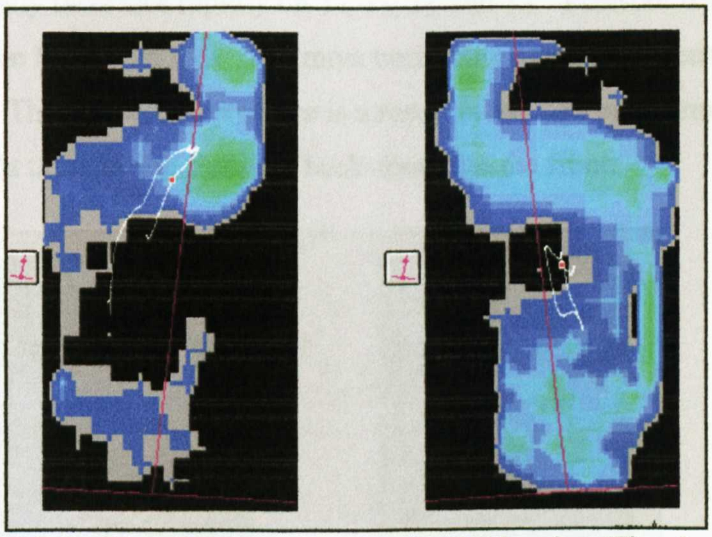


Figure 6.7. In-Shoe Pressures During the Backswing (7iron).

Top of Backswing

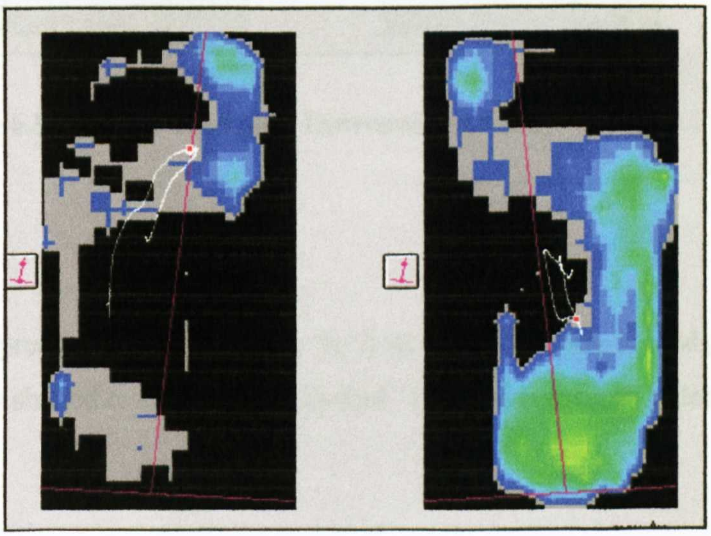


Figure 6.8. In-Shoe Pressures at the Top of the Backswing (7iron).

Downswing

Back-foot

As the club shifts downwards from the horizontal position at the top of the swing, foot pressure is transferred laterally through the downward movement across M_3, M_4, and V_1 until the club reached approximately horizontal. From this position foot pressure decreased rapidly travelling medially across M_4, M_3, M_2, and M_1 away from the calcaneous (H_1, H_2, H_3, H_4). As the downswing progressed the amount of pressure identified within the shoe decreased.

Front-foot

Pressures initially increases rapidly on T_1, T_2, T_3, and T_4. Pressure was also identified on the M_3, M_4 and M_5. The most noticeable pressure increases occur at M_5, V_1, V_2 and H_1. The increase in pressure is a result of the downward motion of the club and weight transferring from the back-foot onto the front.

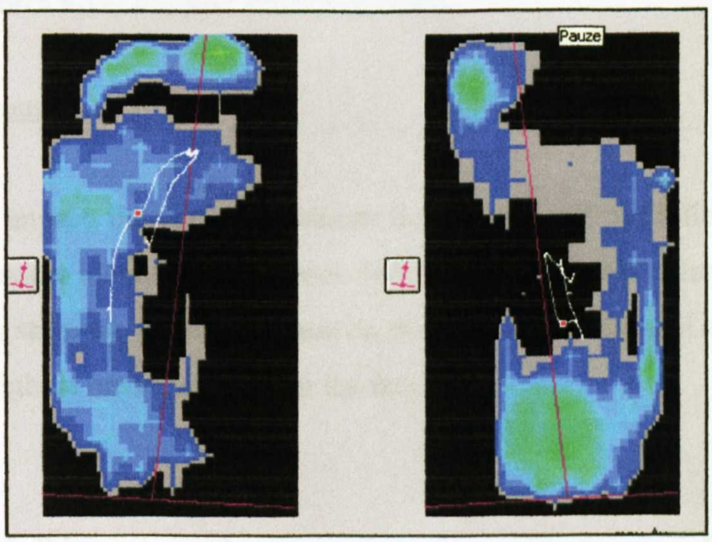


Figure 6.9. Weight Transfer / Downswing (7iron).

Impact

Back-foot

At impact the pressure decreases from the heel region and M_1, and M_2, as the golfers body weight is shifted towards the front-foot. Limited pressure is identified upon T_1.

Front-foot

At impact a large amount of pressure is identified within T_4, T_5, M_4, M_5, V_1, V_2 and $H_{1\text{-}4}$ due to the rapid transfer in bodyweight. The pressure increases further across the lateral edge and heel travelling laterally in the posterior direction.

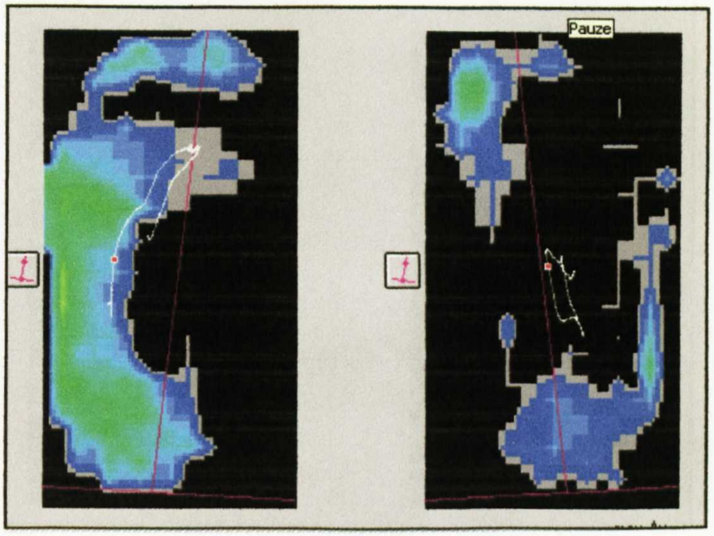


Figure 6.10. Impact / Follow-through.

Follow-through

Back-foot

Following impact, the golfers decelerate the club through the follow-through with limited pressure identified at the back-foot. Slight pressure is identified on T_1, and M_1. At this stage the golfers pressure on the mid forefoot is used to balance while the golfers weight is predominantly on the front-foot.

Front-foot

Following ball impact, rapid increases in pressures travelling medial to lateral occur within M_2, M_3, M_4, and M_5. This pressure progresses instantaneously to V_1, V_2, and in a posterior direction to H_1, and H_3. The lateral posterior transfer in pressure is a result of the club head travelling up and around and behind the golfer. As a result the highest pressure occurred within the lateral edge and heel of the foot.

It is this stage of the swing in which the highest in-shoe pressures are identified. The acute pressures associated with the follow-through are a result of the decelerating anti-clockwise rotation of the club and weight shift of the golfer's body weight.

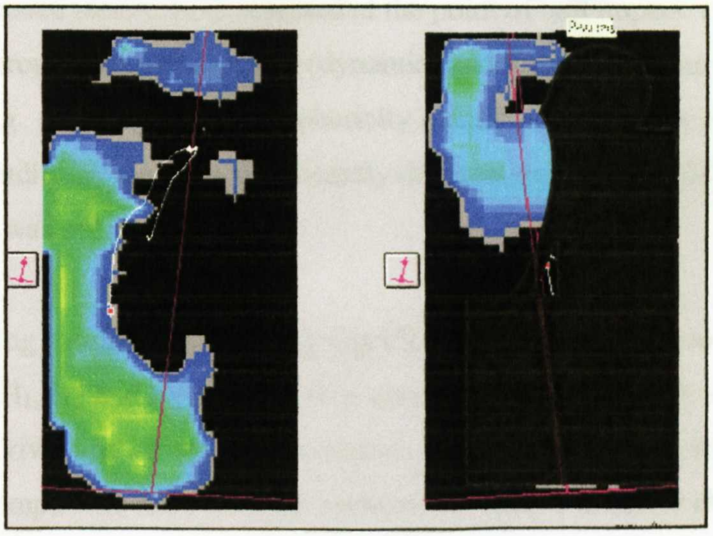


Figure 6.11. Follow-through.

The results confirm that the back-foot heel region was not in contact with the ground following ball impact. Chapter 5 highlighted that the lack of heel contact following ball contact would enable possible shoe sole developments for the heel and forefoot regions (page 147). Such developments would allow the shoe to prevent any clockwise rotation during the backswing, but facilitate the natural forefoot rotations during the follow through stage of the swing process. Shoe sole recommendations are further discussed within chapter 7.

In-shoe Regional Analysis Results

The pressure observations gave a visual appreciation of the vertical pressure locations across the whole foot during the swing process. To gain a more detailed understanding of the pressures occurring within the shoes recorded data on pressure beneath different regions of the foot were assessed. Regional analyses of nine specific in-shoe regions (Figure 6.2) were compared between the three shoe conditions in both right and left shoes during the golf swing process. The nine regions were (1) posterior lateral heel; (2) posterior medial heel; (3) anterior lateral heel; (4) anterior medial heel; (5) lateral mid-foot; (6) medial mid-foot; (7) lateral forefoot; (8) mid forefoot; (9) medial forefoot. Forces were measured in Newtons (N) and normalised by the golfer's body weight.

As forces created from the golf swing process are applied through the golfer's feet, resultant forces are placed upon the shoe and subsequently the ground surface.

In-shoe pressure results were assessed at the point of ball impact, maximum pressures through the whole swing (dynamic) and the average pressures through the whole swing. Mauchly's Test of sphericity identified that the variance of differences between conditions were not significantly different as a result a Greenhouse-Geisser adjustment was not required.

The following results tables identify significant differences in accordance with hypothesis H_1, H_2, and H_3 between shoe conditions within the left and right shoes and within the driver and 7iron club conditions. The coloured boxes within the tables highlight comparable shoe findings between the 7iron and driver club conditions; e.g. if the same significant finding was identified between shoes in the same region of both club conditions they would be highlighted the same colour. The selected colours do not signify any difference in levels of significance. The tables identify the significant difference between shoes and in-shoe regions. The result means, standard

Table Key:
Y = Yellow Shoe: B = Black Shoe: G = Green Shoe.
R = In-shoe Region.
P = Level of Significance (P = <0.05)
↑ = Significantly higher value e.g. G↑Y = G significantly higher value compared to Y.

errors and standard deviations are shown in appendix G. All the golfers tested were right handed, consequently the results are a representation of a right-handed swing with the right foot being the back-foot and the left foot being the front-foot.

Foot Region Maximal Pressure Analysis:

Individual front-foot means, standard deviations and standard errors are identified within appendix G raw table data 6.a, 6.b, 6.c.

	Heel Region			Mid-foot Region		Fore-foot Region			
Shoe	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**
GREEN : BLACK				G↑B P= <.05	G↑B P= <.05				
YELLOW : BLACK				Y↑B P= <.05					
GREEN : YELLOW					G↑Y P= <.05				

Table 6.2: Front-foot 7iron Significantly Different Maximal Pressures Across Foot Regions

Shoe	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**
GREEN : BLACK		G↑B P= <.05		G↑B P= <.05	G↑B P= <.05				
YELLOW : BLACK									
GREEN : YELLOW					G↑Y P= <.05				

Table 6.3: Front-foot Driver Significantly Different Maximal Pressures Across Foot Regions

Tables 6.2 and 6.3 indicate that traditional spiked Green front-foot consistently produced significantly higher pressures within the lateral mid-foot (R5) region when compared to the other shoe conditions within both the driver ($F(2,34) = 14.66$, $P = <.05$) and 7iron ($F(2,34) = 11.65$, $P = <.05$) club conditions accepting H_1 and H_3. The higher pressures are a result of the longer spikes incorporated within the shoe when compared the shorter Yellow alternative spikes and the flat-soled Black shoe. The lateral mid-foot is a critical region of the front shoe. It is this sole region that supports the anti-clockwise rotation and rapid weight transfer of the golfer during the downswing and follow-through. It is this area where the golfer requires shoe stability to allow the controlled deceleration of the club and upper body.

The Green shoe also constantly produced significantly higher pressures when compared to the Black shoe within the anterior medial heel (R4) region within both the driver ($F(2,34) = 5.91$, $P = <.05$) and 7iron ($F(2,34) = 7.58$, $P = <.05$) club conditions, accepting H_1. This was due to the additional traditional spike traction in comparison to the Black flat sole. Shoe traction around the anterior medial heel

(R4) is needed to maintain a stable foot for the golfer to rotate around during the follow-through. Traction within this region prevents the heel slipping anti-clockwise, inwards towards the golfer.

	Heel Region			**Mid-foot Region**		**Fore-foot Region**			
Shoe	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**
GREEN : BLACK			G$\uparrow$B P= <.05					G$\uparrow$B P= <.05	
YELLOW : BLACK								Y$\uparrow$B P= <.05	
GREEN : YELLOW	G$\uparrow$Y P= <.05					G$\uparrow$Y P= <.05		Y$\uparrow$G P= <.05	

Table 6.4: Back-foot 7iron Significantly Different Maximal Dynamic Pressures Across Foot Regions

Shoe	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**
GREEN : BLACK			G$\uparrow$B P= <.05						
YELLOW : BLACK					B$\uparrow$Y P= <.05	B$\uparrow$Y P= <.05		Y$\uparrow$B P= <.05	
GREEN : YELLOW						G$\uparrow$Y P= <.05			

Table 6.5: Back-foot Driver Significantly Different Maximal Dynamic Pressures Across Foot Regions

Tables 6.4 and 6.5 illustrate that within the back shoe conditions the traditional Green shoe produced greater pressures within the medial mid-foot (R6) region when compared to the Yellow alternative spiked shoe within the 7iron ($F(2,34) = 4.31$, $P = <.05$) and Driver ($F(2,34) = 10.06$, $P = <.05$) club conditions, accepting H_3. Although significantly different the medial mid-foot (R6) region is subjected to limited pressures during the swing process as identified by the low pressure values throughout the raw data (Appendix G, raw data tables 6.d, 6.e, 6f).

The Green shoe also consistently produced greater pressures within the anterior lateral heel region when compared to the Black shoe within the 7iron ($F(2,34) = 6.23$, $P = <.05$) and Driver ($F(2,34) = 4.01$, $P = <.05$) club conditions causing acceptance of H_1. Although the in-shoe analysis assessed the whole swing process it was noted that the back-foot heel region was elevated off the grass surface post ball impact. Through raising the heel the golfers were able to facilitate the anticlockwise forefoot rotation during the follow-through stage of the swing process. As the in-shoe pressures were located within the forefoot regions of the shoe during the later stages of the swing the differences identified between the Green and Black shoe conditions occurred during the initial backswing and downswing until ball contact. The findings highlight the traditional metal spike tractional properties and its ability to provide traction during the clockwise backswing and initial downswing.

The alternatively spiked Yellow shoe produced significantly higher pressures within the mid forefoot (R8) region when compared to the flat-soled Black shoe within the 7iron ($F(2,34) = 16.51$, $P = <.05$) and Driver ($F(2,34) = 7.35$, $P = <.05$) accepting H_2. The greater pressure is associated with the additional traction associated with the alternative spikes and sole protrusions incorporated on the Yellow shoe sole. The back shoe mid forefoot is an essential region for the ant-clockwise rotation of the shoe during the follow-through stage of the swing process. The results highlight the mid-forefoot tractional properties through its association with higher in-shoe pressure; it is however questionable whether this shoe trait is fundamental to the golf swing process, as during the follow through the shoe needs to rotate with the club and body movement around the front-foot. In contrast forefoot traction is a requirement of the back shoe during the backswing as the golfer coils around the right leg. Although the movement is slow in comparison to the downswing and follow-through movement, the shoe needs to maintain a stable position.

In-shoe Pressure Analysis at Ball Impact Observations:

Individual means and standard deviations are identified within (Appendix G, raw data tables 6.g, 6.h, 6i).

	Heel Region			Mid-foot Region		Fore-foot Region			
Shoe	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**
GREEN : BLACK									
YELLOW : BLACK									
GREEN : YELLOW					G$\uparrow$Y P= <.05				

Table 6.6: Front-foot 7iron Significantly Different In-shoe Pressures at Time of Ball Impact

Shoe	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**
GREEN : BLACK		G$\uparrow$B P= <.05		G$\uparrow$B P= <.05					
YELLOW : BLACK									
GREEN : YELLOW									

Table 6.7: Front-foot Driver Significantly Different In-shoe Pressures at Time of Ball Impact

Table 6.6 illustrates that within the 7iron club condition the traditional spiked front-foot Green shoe produced significantly higher lateral mid-foot (R5) in-shoe pressures at ball impact when compared to the alternatively spiked Yellow shoe ($F(2,34) = 5.63$, $P = <.05$) accepting H_3. It is within this region where the golfer needs a fixed base to prevent any anti-clockwise rotation. Unexpected slipping would cause affect shot outcomes. The significant difference was not observed during the driver club condition.

Table 6.7 indicated that with the driver the traditional spiked Green shoe was associated with significantly greater pressure than the flat-soled Black shoe within the posterior medial heel (R2) ($F(2,34) = 8.49$, $P = <.05$) and anterior medial heel (R4) ($F(2,34) = 10.28$, $P = <.05$) regions accepting H_1. Traction in the heel regions is required to prevent the shoe slipping anti-clockwise with the rotation of the club and golfer.

	Heel Region			Mid-foot Region		Fore-foot Region			
Shoe	R1	R2	R3	R4	R5	R6	R7	R8	R9
GREEN : BLACK								G↑B P= <.05	
YELLOW : BLACK								Y↑B P= <.05	
GREEN : YELLOW									

Table 6.8: Back-foot 7iron Significantly Different In-shoe Pressures at Time of Ball Impact

Shoe	R1	R2	R3	R4	R5	R6	R7	R8	R9
GREEN : BLACK		B↑G P= <.05		B↑G P= <.05				G↑B P= <.05	
YELLOW : BLACK								Y↑B P= <.05	
GREEN : YELLOW								Y↑G P= <.05	

Table 6.9: Back-foot Driver Significantly Different In-shoe Pressures at Time of Ball Impact

Raw back-foot in-shoe pressures at ball impact are shown in Appendix G, raw data tables 6.j, 6.k, 6l. Tables 6.8 indicates that at the time of ball contact using a 7iron club the traditional spiked Green shoe and alternative spiked Yellow shoe produced significantly higher in-shoe mid forefoot regional pressures when compared to the Black shoe condition ($F(2,34) = 7.27$, $P = <.05$). The results were replicated within the Driver club condition (Table 6.9) with the Green and Yellow shoes producing significantly higher in-shoe pressures when compared to the Black shoe condition ($F(2,34) = 3.47$, $P = <.05$) accepting H_1 and H_2.

As previously identified the mid forefoot region of the back shoe must allow the anticlockwise rotation during the follow-through stage of the swing process. However, at ball contact the back-foot must maintain a stable position to allow accurate club head placement. As a result the higher pressures identified within the mid forefoot at the time of ball impact is a functional sole trait.

Average In-shoe Pressure Observations:

Individual means and standard deviations are identified within appendix G, raw data tables 6.m, 6.n, 6.o.

	Heel Region			Mid-foot Region		Fore-foot Region			
Shoe	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**
GREEN : BLACK		G↑B P= <.05		G↑B P= <.05	G↑B P= <.05				
YELLOW : BLACK				Y↑B P= <.05				Y↑B P= <.05	
GREEN : YELLOW									

Table 6.10: Front-foot 7iron Significantly Different Average In-shoe Pressures

Shoe	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**
GREEN : BLACK	B↑G P= <.05	G↑B P= <.05	B↑G P= <.05	G↑B P= <.05					
YELLOW : BLACK		Y↑B P= <.05		Y↑B P= <.05					
GREEN : YELLOW									

Table 6.11: Front-foot Driver Significantly Different Average In-shoe Pressures

For the front-foot with both clubs the average in-shoe pressures identified the traditional Green shoe to produce significantly higher posterior medial heel (R2) (7iron F(2,34) = 3.66, P = <.05 and Driver F(2,34) = 7.91, P = <.05) and medial anterior heel (R4) (7iron F(2,34) = 10.20, P = <.05 and Driver F(2,34) = 3.50, P = <.05) in-shoe pressure when compared to the flat-soled Black shoe condition causing accepting H_1 (Tables 6.10 and 6.11). The Green shoe also produced significantly higher medial pressures (R5) within the 7iron (F(2,34) = 5.48, P = <.05) when compared to the Black shoe (table 6.10). For the front-foot with both clubs the alternatively spiked Yellow shoe also produced significantly greater average in-shoe pressures within the anterior medial heel (R4) region when compared to the flat-soled Black shoe accepting H_2 (table 6.11).

	Heel Region			Mid-foot Region		Fore-foot Region			
Shoe	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**
GREEN : BLACK			G$\uparrow$B P= <.05					G$\uparrow$B P= <.05	
YELLOW : BLACK						B$\uparrow$Y P= <.05		Y$\uparrow$B P= <.05	
GREEN : YELLOW						G$\uparrow$Y P= <.05		Y$\uparrow$G P= <.05	

Table 6.12: Back-foot 7iron Significantly Different Average In-shoe Pressures

Shoe	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**
GREEN : BLACK			G$\uparrow$B P= <.05						
YELLOW : BLACK			Y$\uparrow$B P= <.05			B$\uparrow$Y P= <.05		Y$\uparrow$B P= <.05	
GREEN : YELLOW						G$\uparrow$Y P= <.05			

Table 6.13: Back-foot Driver Significantly Different Average In-shoe Pressures

Raw back-foot average data is shown in appendix G, raw data table's 6.p, 6.q, 6.r. Within the back shoe condition the traditional spiked Green shoe produced significantly higher pressures within the anterior lateral heel (R3) region with the 7iron ($F(2,34) = 7.47$, $P = <.05$) and Driver ($F(2,34) = 8.12$, $P = <.05$) club conditions when compared to the flat-soled Black shoe condition accepting H_1 (tables 6.12 and 6.13).

The traditional spiked Green shoe produced significantly higher average pressure within the 7iron ($F(2,34) = 5.02$, $P = <.05$) and Driver ($F(2,34) = 7.74$, $P = <.05$) club conditions within the medial mid-foot region (R6) when compared to the Yellow alternatively spiked shoe accepting H_3. In addition the flat-soled Black shoe produced greater medial mid-foot region (R6) pressures when compared to the alternatively spiked Yellow shoe condition rejecting H_2 (tables 6.12 and 6.13). The results highlight limitations with the alternative spiked shoe condition. However as previously identified the medial mid-foot (R6) region was subjected to limited pressures during the swing process as identified by the low pressure values throughout the raw data (Appendix G). Consequently this shoe sole region requires limited traction throughout the swing process.

In addition significantly higher mid forefoot (R8) average pressures were identified within the 7iron ($F(2,34) = 17.06$, $P = <.05$) and Driver ($F(2,34) = 7.74$, $P = <.05$) club conditions within the Yellow alternatively spiked shoe when compared to the flat-soled Black shoe condition accepting H_2.

Ground Action Force Observations:

Statistically significant ($P < 0.05$) main effects were identified within the back-foot, driver Tz range values ($F(2,34) = 12.43$, $P = <.05$). Significant main effects were identified between the Green (14.82 ± 0.44) traditional spiked shoe and the Black (13.21 ± 0.48) flat-soled shoe condition. No significant differences were identified between shoe conditions within the front-foot Tz range values. Raw ground action force data is shown in appendix H.

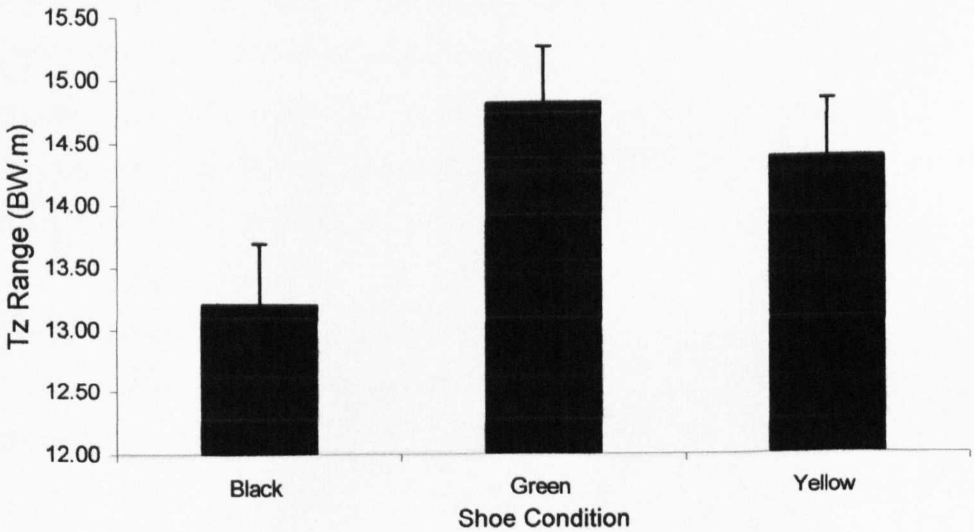


Figure 6.12. Driver Back-foot Tz Range.

Back Foot	Driver Tz Range (Mean ± SE)	7iron Tz Range (Mean ± SE)
Black	*13.21 ± 0.48	12.60 ± 0.43
Green	*14.82 ± 0.44	13.05 ± 0.31
Yellow	14.39 ± 0.45	13.03 ± 0.32

Table 6.14. Back-foot Tz Range Results (N.m).

* Denotes where the Significant Differences Occurred.

No significant differences were identified within the front or back-foot 7iron Tz range results.

Front-foot	Driver Tz Range (Mean ± SE)	7iron Tz Range (Mean ± SE)
Black	39.28 ± 1.00	36.37 ± 1.08
Green	38.15 ± 1.41	36.83 ± 1.09
Yellow	38.94 ± 1.30	36.64 ± 0.95

Table 6.15. Front-foot Tz Range Results (N.m).

The results highlight the similarities between the shoe sole interfaces when compared during the actual golf swing process. The similarities between shoe sole interfaces complement the in-shoe pressure analysis findings with no shoe sole consistently producing significantly greater functional performance.

6.6: Discussion

The in-shoe pressure observations identified from the pressure screens (figures 6.4 - 6.9) produced a qualitative analysis of the pressures occurring within the shoe throughout the swing process. It was possible to gain a detailed observational understanding of the pressures subjected to each of the 16 anatomical landmarks of the foot and the nine foot regions. The results further emphasise the different demands on the front and back feet / shoes. The highest pressures were associated with the lateral regions of the front-foot from the point of ball impact. The lateral edge of the foot was required to absorb the golfers bodyweight and the anti-clockwise rotational forces of the swinging club.

In conjunction with the observational in-shoe analysis, a detailed quantitative analysis of the pressures occurring within the shoe was gained. In-shoe pressures were synchronised with shoe-ground action forces to gain a detailed qualitative understanding of the shoe-ground / shoe-golfer interaction. The following explanations identify functional regional properties of the tested shoe sole interface designs specific to different stages of the swing process.

In-shoe Regional Pressure Results

Front Shoe Maximal In-shoe Regional Pressures.

Traditional metal spiked Green shoe consistently produced significantly higher in-shoe pressures within the medial heel regions (R2, R4x2) and lateral mid-foot (R5x4). Traction within the front shoe is critical throughout the downswing and follow-through stages of the swing process as it is the main base of support for the golfer. The stable base allows the golfer to decelerate the club and torso rotations through applying resistance through the front leg and shoe. These forces are highest following ball impact and through the follow-through swing phase. Due to the anticlockwise rotation forces predominantly applied to the medial heel and lateral mid / forefoot (Figure 6.13).

Figure 6.13: Green Shoe Areas of Pressure Through Anticlockwise Shoe Rotation

The Green shoe incorporated 8mm metal spikes along with sole mouldings. Figure 6.14 shows the angle and positioning of the mouldings is in opposition to the direction of the anticlockwise rotations.

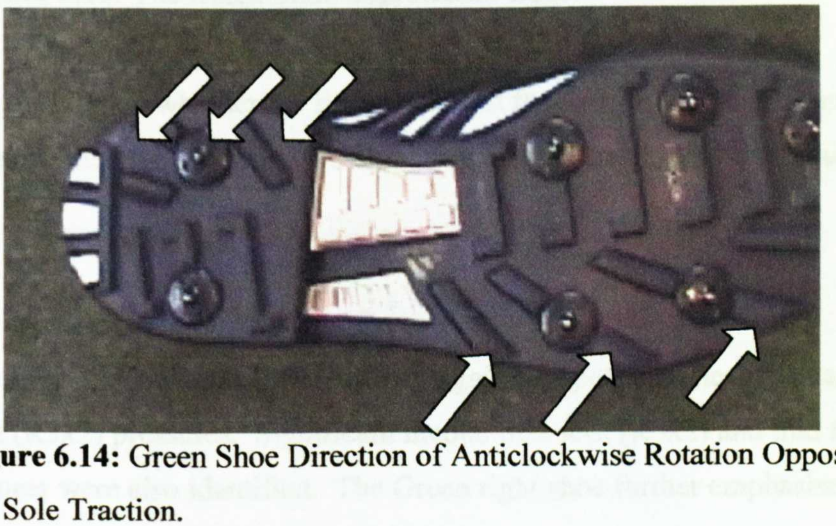


Figure 6.14: Green Shoe Direction of Anticlockwise Rotation Opposite to the Sole Traction.

The alternatively spiked Yellow shoe produced significantly more pressure within the anterior heel region (R4). The limited significant findings raise concerns regarding the functional performance of the sole traction design. One would expect the shoe condition to consistently outperform the flat-soled shoe condition throughout the shoe regions.

Black shoe analysis identified significant pressures within the posterior lateral heel (R1) and the lateral mid-foot regions (R5). The higher pressure associated within the lateral regions are a result of no additional traction on the sole bed. Through observing the recorded shoe movements it was observed that the spike-less flat sole lay closer to the grass surface causing the lateral sole edge to act as a form of resistance against the anticlockwise rotations. The sole edge caused the shoe/foot to invert onto the lateral sole edge during the follow-through phase of the swing. This resulted in the increased pressures along the lateral sole edge.

Figure 6.15: The Black Shoe Sole Lateral Edge.

It could be questioned whether the flat sole would function in the same manner on harder ground when the sole edge would be less able to embed into the ground surface.

Back Shoe Maximal In-shoe Regional Pressures.
The Green shoe regional analysis identified significant posterior heel (R1) anterior lateral heel (R3x2) pressures. Significant medial mid-foot (R6x2) and mid forefoot (R8) pressures were also identified. The Green right shoe further emphasises the increased performance of the traditional spikes.

The asymmetrical demands placed upon the back shoe during the swing process cause difficulties in developing a shoe that functions according to the stage of the swing process. During the backswing the whole back shoe remained in contact with the ground surface. During this stage the golfer required good traction to enable the club and golfer to coil around the fixed foot / leg as identified within the traditional metal spiked shoe. The traditional spiked Green shoe provided this increased traction predominantly within the heel regions. Following the backswing the whole shoe remained in contact with the ground until ball contact was made. Subsequently the club and body rotations transferred onto the front-foot causing the back-foot to rotate on the forefoot of the shoe. Limited traction is required during this stage of the swing as the foot is required to rotate unrestricted anticlockwise until the club and golfer's rotation has stopped. It is possible that alterations in the level of sole traction between the heel and fore foot within the back shoe would enable the shoe to function as required by the swing.

The Yellow alternatively spiked shoe was identified to produce significantly higher in-shoe pressures within the mid forefoot region (R8x3) when compared to the other shoe conditions. The findings highlight positive shoe sole interface characteristics during the back-swing and early stages of the follow-through of the swing process. The increased tractional properties of the Yellow shoe would however restrict the natural anticlockwise forefoot rotations during the later stages of the swing process.

The flat-soled Black shoe produced significantly higher pressures within the medial and lateral mid-foot (R5, R6) regions. The higher traction identified would enable the back shoe to maintain a stable position during the back-swing. The golfer requires a stable foot during this stage of the swing process to pivot and rotate around through the back-swing, preparing for the explosive downward swing movements. The increase in sole traction within this region is a result of the increased soles surface area as it is situated closer to the ground surface as the shoe does not incorporate any additional sole mouldings or spikes. Within the medial mid-foot region (R6) limited pressures are imposed on the shoe during the swing, reducing the need for high sole traction.

Front Shoe Regional In-shoe Pressures at Ball Impact

Pressures within the shoe sole were measured at the point of ball impact

Green shoe regional analysis identified significant anterior and posterior medial heel (R2) (R4), lateral mid-foot (R5) pressures. The results mirror those identified within the dynamic region analysis, further supporting the tractional properties of the traditional spiked shoe within these regions.

No significantly higher pressures were identified within the alternatively spiked Yellow shoe condition. The results highlight possible concerns regarding the shoe's sole tractional properties, as at ball impact it offers the golfer the same performance as a flat-soled shoe.

Back Shoe Regional In-shoe Pressures at Ball Impact

The traditional Green and alternatively spiked Yellow shoe produced significantly higher mid forefoot (Green R8x2) (Yellow R8x3) regional pressures (figure 6.16). During the later stages of the swing process, through the follow-through the right shoe is required to rotate as the golfers weight transfers onto the front-foot. However at ball impact a stable flat base is required, thus the results identify positive sole characteristics of both sole traction types.

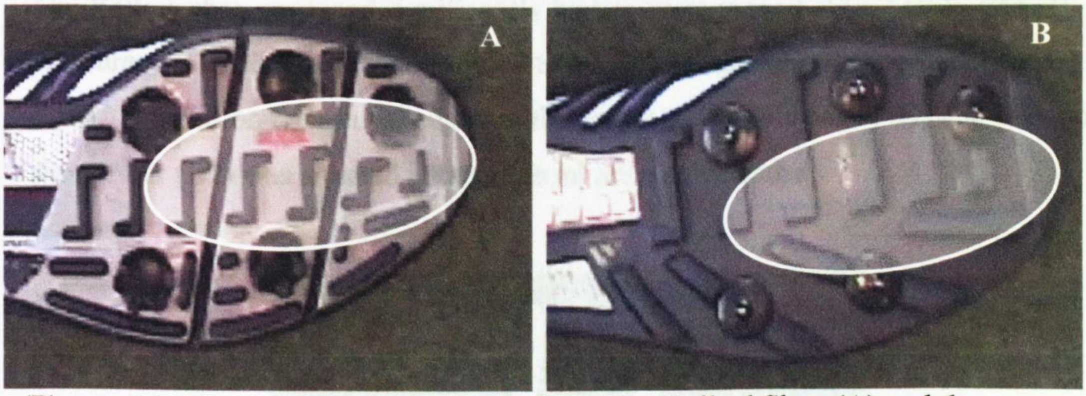


Figure 6.16: Region 8 on the Yellow Alternative Spiked Shoe (A) and the Traditional Spiked Green Shoe (B).

The flat-soled Black shoe produced significantly higher posterior medial heel (R2) and medial anterior heel (R4) pressures (Figure 6.17). The higher pressures are a result of the sole not incorporating any additional traction resulting in the heel laying flat on the grass surface. Video recordings identified the medial heel edge to embed into the grass during the backswing and downswing.

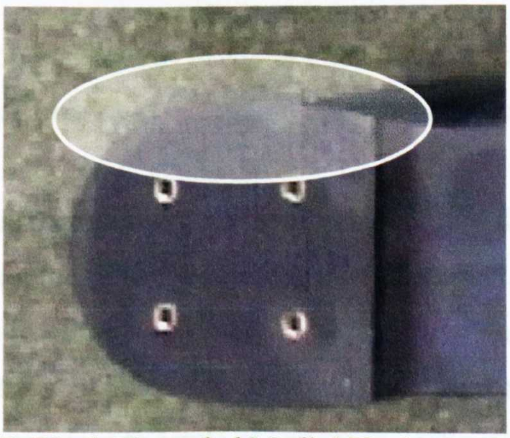


Figure 6.17: Black Flat-soled Medial Heel Regions 2 and 4.

Front Shoe Average In-shoe Regional Pressures

Average pressures within the shoe were assessed throughout the whole swing process. Although not identified within the research hypothesis it was thought the analysis of the average in-shoe pressures during the swing process would be of interest in the understanding of the interactions between the foot and shoe. Greater average in-shoe pressures were associated within the Green shoe medial heel (R2x2), (R4), lateral mid-foot (R5) regions. The results further support the Green shoe findings within the dynamic swing analysis further enforcing the tractional properties of the shoe within these regions.

The Yellow shoe produced significantly higher average medial heel (R2), (R4x2) pressures . The shoe sole incorporated two medial edge sole traction bars (Figure 6.16). One bar on the medial edge ran the length of the sole edge (B1) and a second shorter bar (B2) was situated adjacent to an alternative spike.

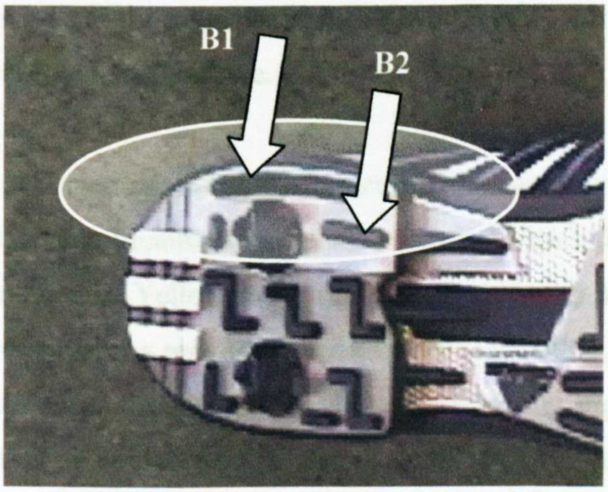


Figure 6.18: The Yellow Shoe Medial Heel Traction Design.

The two bar traction placements in conjunction to the spike placement produced a functional means of creating sole traction opposing heel rotational forces.

The Yellow shoe also produced significantly higher mid forefoot (R8) regional pressures supporting the right shoe findings at ball impact. However within the left shoe condition the forefoot is subjected to higher linear and rotational forces as the golfer and club rotate and decelerate predominantly on the left foot. Unlike the right, the left shoe is not required to rotate at any stage of the swing process. As a result the left Yellow shoe produces critical mid forefoot traction to reduce linear or rotational slipping during the swing process.

The Black produced significantly higher lateral heel (R1), (R3) regional pressures. As previously identified the lower sole position caused by the flat sole bed resulted in the golfer inverting the shoe sole, causing the sole edge to penetrate to grass, creating a form of traction on the lateral edge.

Back Shoe Average In-shoe Regional Pressures

The Green shoe analysis identified the anterior lateral heel (R3x2), medial mid-foot (R6x2) and mid forefoot (R8) regions to provide significantly high in-shoe pressures. The anterior lateral heel findings (R3) further support the previous maximum pressure observations.

The results further support the back shoe pressures identified throughout the dynamic swing and at ball impact regional analysis, further confirming the tractional properties of the traditional spiked sole.

The Yellow shoes average regional analysis identified the anterior lateral heel (R3) mid forefoot region as significantly higher. As identified within the whole dynamic swing and at ball impact the Yellow shoe produced significantly high mid forefoot (R8x3) regional pressures. As previously discussed this is both a positive and negative trait dependent on the stage of the swing process. During the back-swing, downswing and until ball contact mid forefoot traction is required. Post ball contact the shoe is required to rotate to allow the golfer and club an unrestricted fluid anticlockwise rotation around the left foot.

The Black shoe was identified as producing significantly higher medial mid-foot (R6), pressures within both club conditions and higher medial mid-foot (R6) regional pressures within the 7iron club condition when compared to the alternative spiked Yellow shoe. The results support previous results identified within the dynamic back shoe regional findings within the present study. The findings support the larger surface area in contact with the ground through no additional 'raised' sole traction.

As previously discussed the requirements for high sole traction within the region are minimal due to the limited demands placed upon the shoe during the swing process. However the results raise concerns regarding the tractional properties of the alternatively spiked Yellow shoe within this shoe region.

Ground Action Force Observations:

The traditional spiked Green shoe produced a significantly greater Tz range within the back-foot when compared to the flat-soled Black shoe conditions when using a driver, causing acceptance of H_1. The Tz range incorporated the rotational torques of both the backswing and downswing movements during the swing process. The results highlighted the tractional properties of the traditional spiked shoe sole during rotational movements. The results support previous findings in chapter 5 which also identified significant differences between the traditional and flat-soled shoe conditions.

No other significant differences were identified within the rotational ground action torque variables. As identified within chapter 5 the limited differences between shoe conditions raise concerns regarding the functional performance of traditional and alternatively spiked golf shoes when compared to a flat-soled shoe condition.
The results further reflect chapter 5 findings with higher ground action torques and forces identified within the front-foot when compared to the back-foot. The findings add further support for asymmetrical shoe sole interface designs with greater support and traction required within the front shoe sole. The recorded ground action force findings correspond to the values identified within chapter 5 suggesting limited foot / shoe alterations when pressure insoles are incorporated within the shoe. The results suggest limited differences in the foot or shoe movements and subsequent forces and torques when the insole was used. The corresponding findings between chapters lend support for the use of such shoe insoles in identifying task specific analysis of sporting movements.

Future Research and Limitations within the Current Testing Modality:

The study identified regional pressures that occurred during the swing process. The shoe insoles were able to measure the in-shoe pressures without inhibiting the natural foot or body movements during the swing process. Such unrestricted movements enabled the golfers to consistently perform their natural swings during the data collections. Due to time and location constraints it was not possible to identify differences in shot performance (shot length, accuracy) between shoe conditions within the present study. It was not possible to relate the current findings in detail with any previous research due to limited reported findings and paucity in in-shoe pressure literature.

Through using insoles that had not been exposed to high impacts during running or jumping and less than two hours of use the previous, limitations identified by McPoil *et al* (1995) regarding in-shoe pressure reliability were not identified within the present study. A number of limitations were identified within the in-shoe pressure software. It must be recognised that the pressure insoles require the deformation of its pressure sensors, which will in effect act as an in-shoe cushioning element. Subsequently it will modify the magnitude of the pressure that it attempts to measure (Hennig, 1998). When comparing pressure analysis and ground action forces it is important to recognise that in-shoe pressure systems are unable to measure shear forces within the shoe only vertical forces. Consequently pressure analysis systems underestimate the actual forces generated by the performer.

The system was also only able to give a pictorial representation of the centre of pressure (COP) movement between the front and back feet during the golf swing. Only qualitative COP measures were calculated during gait analysis. The footscan software's calibration algorithm could only calculate dynamic measurements. As a result the system determines any static pressure through calculating the recorded subject body weight within the insole system. It is possible that the systems inability to measure static pressures would reduce the systems measurement accuracy during regions of static weight placement within specific in-shoe regions. In-shoe pressure systems have largely been limited to gait analysis resulting in such software limitations when analysing the feet in fixed positions. However the in-shoe pressure analysis system provided a reliable means of identifying specific regional pressures between the foot and shoe interaction. The in-shoe results should not however be directly compared to the forces measured on the force platforms. The ground action forces measure the interaction between the shoe and the ground whereas the shoe insoles measure the interaction between the shoe and foot and should be evaluated as different entities. However the two systems used in conjunction with each other provided a comprehensive understanding of the functional performance of the footwear when dynamic forces were applied.

6.7: CONCLUSION

The aim of the study was to investigate regional in-shoe plantar pressures between three different shoe sole interface conditions during the golf swing process. The data analysis revealed previously unreported in-shoe pressures occurring between the golfer and shoe-sole during the golf swing process. The traditional spiked shoe produced significantly higher regional in-shoe pressures results when compared to the flat-soled and alternatively spiked soles. However the findings did not identify any shoe sole condition that consistently produced significantly higher in-shoe pressures. All sole conditions provided significantly higher pressures within specific in-shoe regions at different stages of the swing process. The flat-soled shoe provided comparable results to the spiked shoe sole conditions within various in-shoe regions further highlight previous sole design concerns identified within chapter 5.

Individual positive and negative sole traction characteristics were identified for each shoe sole interface. The observations offer an insight into possible traction locations situated over areas of high in-shoe pressure. It may then be possible to develop a sole that provides the golfer the traction required throughout the swing process. Further sole interface development possibilities based on the thesis findings are discussed in greater detail within the next chapter. The interaction between the shoe and ground identified comparable ground action force measures between the present study and chapter 5. The findings suggest limited foot adaptations during the swing process when a pressure insole is incorporated within the shoe, lending support for the use of such pressure system within dynamic activities.

The pressures identified within the front-foot were found to be greater when compared to the back-foot supporting Pforringer and Rosemeyer's (1989) observations. The in-shoe pressures identified between the front and back shoes were found to be located at different regions throughout the swing process. The different requirements and demands subjected to the front and back shoe conditions support chapters 2 and 5. The findings strengthen past conclusions for asymmetrical golf shoe sole interface designs.

CHAPTER 7: DISCUSSION AND CONCLUSION

7.1: GENERAL DISCUSSION

The aim of this thesis was to establish the performance characteristics of different golf shoe sole interface designs of both the front and back shoes on natural grass. The interactions between the shoe and the ground have been recognised as the vital link that allows a golfer to perform the body movements during the golf swing that lead to impact with the ball (Dillman and Lange, 1994). Limited scientific analysis of golf shoe sole interfaces had previously been conducted on natural grass surfaces, although a small number of investigations had occurred using artificial grass (Williams and Cavanagh, 1983, Barrentine *et al.*, 1994) and researched single foot movements (Williams and Cavanagh, 1983).

Initial investigation into the movements and requirements of the leg, foot and shoe sole interface designs during the golf swing was conducted. The study involved kinematic analysis of these movements, with the aim of identifying typical movement patterns within a wide golfing population. The actions identified between golfers allowed a quantitative biomechanical model of typical lower body movements to be identified. Golfers shoe traction was categorised into traditional metal spiked or alternative spiked shoes. The front and back-foot movements were observed to be asymmetrical with differing demands placed each foot during the swing, supporting Williams and Cavanagh's (1983) previous observations.

The study observed the back-foot to be subjected to slower, less demanding movements throughout the whole swing process when compared to the front-foot. Throughout the downswing and follow-through (the fastest stages of the swing) the back-foot acted as a point of balance while the front-foot was required to support the golfers weight while acting as a secure rotational point for the golfer and club to accelerate and decelerate around. It was at these stages of the swing where any slipping or irregular movement would cause detrimental affects to the shot outcome. The findings supported the observations of Cochran and Stobbs (1968), Williams and Cavanagh (1985) and Slavin and Williams (1995) who identified the importance of the foot and lower leg actions in generation of power, control and support throughout the swing.

Through studying the golf swing movements an observational analysis of the traction performance of traditional and alternative shoe sole interfaces were identified. Both types of shoe traction were observed to slip or demonstrate irregular foot movements during the swing process. The study reported it was unlikely that the shoe sole interface designs worn by the golfers provided the traction and support required for the golf swing process.

A detailed assessment of different modern golf shoe sole interfaces was required to understand their specific performance characteristics when subjected to golf swing specific movements. From the lower body movements and requirements of the golf shoe sole interface previously identified, a traction-testing device was used to reproduce linear and rotational movements within chapter 4. As golf is played on a natural grass surface, methodological problems had to be overcome to enable the collection of shoe sole interface data in an ecologically valid environment. As a result the shoe conditions were assessed on a grass covered force platform replicating the ground surface of a golf course.

Ground action forces identified the flat-soled (Black) shoe to consistently produce less traction when compared to the traditional metal spiked (Green) and the alternatively spiked (Red, Blue, Yellow) shoes. Alternative spiked shoes were however unable to provide comparable traction to the traditional metal spiked shoe supporting Slavin and Williams (1995).

Swing specific linear and rotational movements were applied to the forefoot and whole foot of the shoes, it was however questioned if the findings could be directly related to the dynamic forces applied by a golfer during a golf swing. The only accurate method to apply forces and movements created during the swing was to test the shoes while being worn by golfers within a real life dynamic golf swing situation. Within chapter 5, synchronised ground action force analysis of both front and back shoe sole interfaces was performed on natural grass.

From previous findings within the thesis (chapter 2) it was not possible to identify differences in the forces created at the sole interface by different standards of golfing ability or length of clubs used. Chapter 5 assessed these variables with each of the five different shoe sole interfaces previously assessed within the traction tests. In contrast to chapter 4 the study only identified two between shoe variables to be significantly different. The results confounded chapter 4 results, which measured fewer variables but identified ten significant differences between shoe sole conditions. The contradictory results highlight important differences in mechanical and dynamic testing of shoe sole traction. As a consequence mechanical testing results should be reviewed with caution. Such testing methodologies are useful in gaining repeatable between shoe comparisons but the findings should not be directly related to the dynamic movements occurring during the golf swing process.

While shot outcomes varied between handicap groups, the study revealed that the ground action forces created at the shoe sole interface were not significantly different between golfing ability. As a result the differences in performance outcome were a result of how consistently the golfers were able to utilise and control the forces developed from the shoe soles interface interaction with the ground.

Although not directly related to golf shoe performance the results identified significant differences between the weight transfer times between handicap groups. The more able low handicap group produced significantly slower weight transfer times when compared to the medium and high handicap golfers. The findings offered an appreciation of the processes involved for a constantly successful shot. A slower more controlled transfer of body weight from the back-foot to the front allowed greater control of the forces created at the feet during the swing process resulting less error at ball impact. In comparison the faster weight transfer found within the less able players suggested excessive movements resulting in uncontrolled or less repeatable ball contact.

Although weight transfer times are related to golfing technique rather than a direct determinate of the shoe designs (as highlighted in the non significant findings between shoe conditions), an improvement in shoe design may facilitate a more natural and supportive base to aid the golf population as a whole.

The study further supported chapters 2 and 4 observations highlighting the need for asymmetrical shoe sole interface design. The sole interfaces need to have different frictional properties depending on the stage of the swing process and whether it is the front or back-foot. The concurrent findings support the observations made by Carlsoo, (1967), Williams and Cavanagh, (1983), Konig and Tamres (1992), and Thomas and Pietrocarlo, (1996).

A detailed understanding of the shoe sole interface's interaction with the ground surface was gained during chapters 4 and 5. To understand the complete performance characteristics of the sole interfaces an understanding of their interaction with the actual golfer was required. In-shoe plantar pressures were measured in chapter 6 using pressure insoles situated within both the front and back golf shoes. The insoles measured dynamic pressures across both feet throughout the golf swing process.

The study identified specific regional pressures at different stages of the swing process within flat-soled, traditional and alternatively spiked shoes. An understanding of the in-shoe pressure locations within each shoe during the swing process was gained, identifying higher in-shoe pressure demands within the front shoe. The results further highlighted the asymmetrical demands placed upon the front and back feet supporting chapters 2,4 and 5.

Significant in-shoe pressure differences were identified within all three types of shoe sole interfaces tested at different in-shoe regions and at different stages of the swing process. The study further identified the inconsistencies within golf shoe sole traction performance with no single shoe sole consistently producing higher in-shoe pressures within all the sole regions. As identified within chapter 5, the flat-soled shoe provided comparable or greater traction when compared to the traditional and alternatively spiked shoe conditions within a number of measured variables. Such findings further emphasised golf shoe sole interface design concerns.

The in-shoe analysis identified golfers were able to adapt to the forces produced during the swing within the three sole traction conditions assessed. Only through such in-shoe analysis can an understanding of the shoe-foot interactions be gained.

Shoe Sole Interface Design Recommendations.

The thesis assessed five shoe sole interface designs within three different testing modalities (mechanical, dynamic ground action force and in-shoe pressure analysis).

However, no single shoe sole condition was identified to consistently produce greater tractional performance at the sole interface throughout the testing. The Green traditional spiked shoe was identified to provided the greatest tractional properties within the mechanical testing (Chapter 4). It would therefore be plausible to base shoe sole design recommendation on this sole design. However, the traditional metal spikes used within the Green shoe are banned on many golf courses as a result of course surface damage. It was therefore not possible to incorporate the traditional longer metal spikes integrated within the Green shoe within the shoe sole design recommendations.

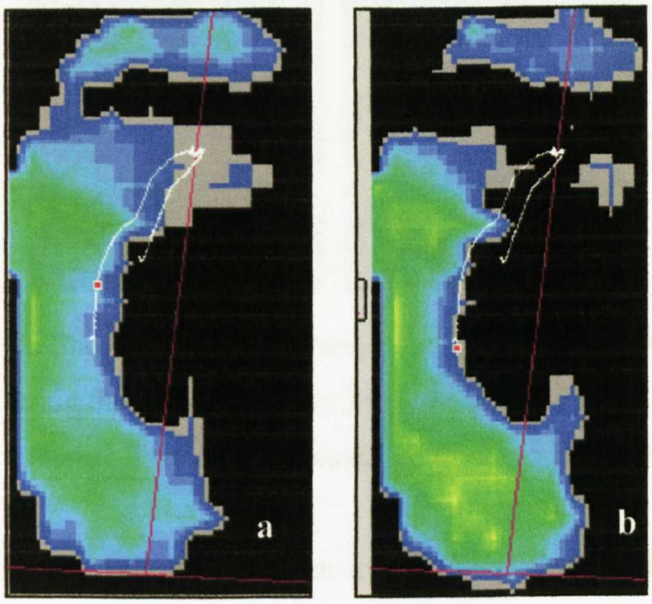
Positive and negative aspects of each of the five shoe tested enabled an understanding of possible sole interface alterations and modifications needed to facilitate some and inhibit other the linear and rotational forces produced during the golf swing.

The following shoe sole recommendations are based on the thesis findings.
A functional mode of sole traction was identified through using traction bar mouldings located on the shoe sole interface positioned to oppose the identified directions of linear and rotational forces. Possible 'T' or 'X' shaped mouldings in conjunction with alternative spikes would oppose both lateral and rotational forces created during the swing process.

The flat-soled Black shoe unexpectedly produced significantly higher in-shoe pressures when compared to the soles incorporating traction. The comparable findings were due to the shoe sole being situated lower on the ground increasing the surface contact area. Consequently the incorporation of a mid-sole traction section (Table 7.2) within both the front and back shoes would increase the surface area of the sole increasing traction.

Front Shoe Sole Interface Recommendations

Figures 7.1a and 7.1b identify the regions of highest pressure within the front shoe at ball impact and during the follow-through the most demanding phases of the swing process, identified within chapter 6. It is at these regions where traction must be most proficient.



Figures 7.1a and **7.1b** show the Highest Pressures were identified Around the Time of Ball Contact and as the Club and Golfer Started to Decelerate During the Follow-through.

In-shoe pressures highlight the need for high traction throughout the lateral sole edge, across the lateral mid-foot and toes and within the heel region.

To limit the shoe sole slipping upon the interface regions that are subjected to the highest forces during the swing, spikes and sole mouldings need to be located at an angle opposing the applied forces. The highest front-foot pressures were identified during ball impact and the follow-through stages of the swing process.

Back Shoe Sole Interface Recommendations

Figures 7.2a and 7.2b identify the regions of highest pressure within the back shoe during the backswing the most demanding phases of the swing process as identified within chapter 6. It is at these regions where traction must be most proficient.

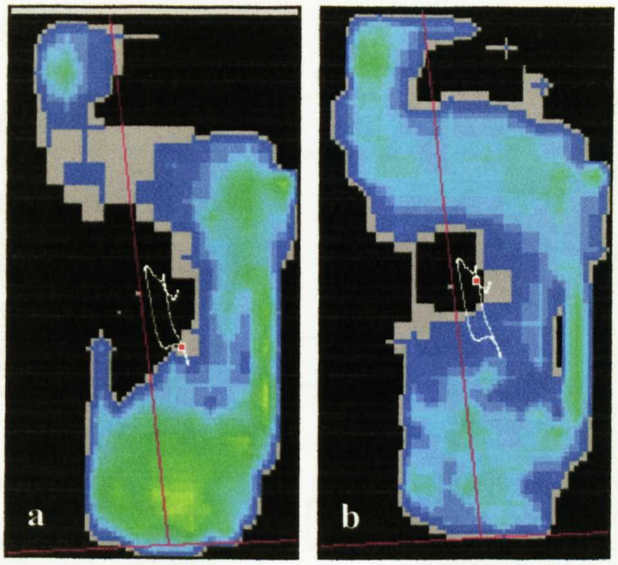


Figure 7.2a Shows the Highest Pressures Were Identified within the Heel Region During the Later Stages of the Backswing. **Figure 7.2b** Shows Reduced Pressure Travelling Towards the Forefoot During the Downswing.

The back-foot shoe sole interface pressure analysis identified the highest traction was required across the lateral sole edge, the lateral mid-foot and within the heel region.

During the follow-through the shoe is required to rotate on the medial forefoot, but remain in a stable position during the backswing. The back shoe sole therefore requires an interface that facilitates medial forefoot anticlockwise rotation. However, throughout the backswing and the early stages of the downswing the back shoe must remain stable. Chapter 6 identified the whole sole to be in contact with the ground during the backswing but only the forefoot was in contact during the follow-through. As a result, by incorporating greater traction within the heel and lateral forefoot and a flat medial forefoot region, the shoe would be stable during the backswing when the whole sole is in contact but also facilitate forefoot rotational movements during the follow-through when the heel is elevated.

Figures 7.3 and 7.4 show pictorial representations of possible sole developments based upon the thesis findings.

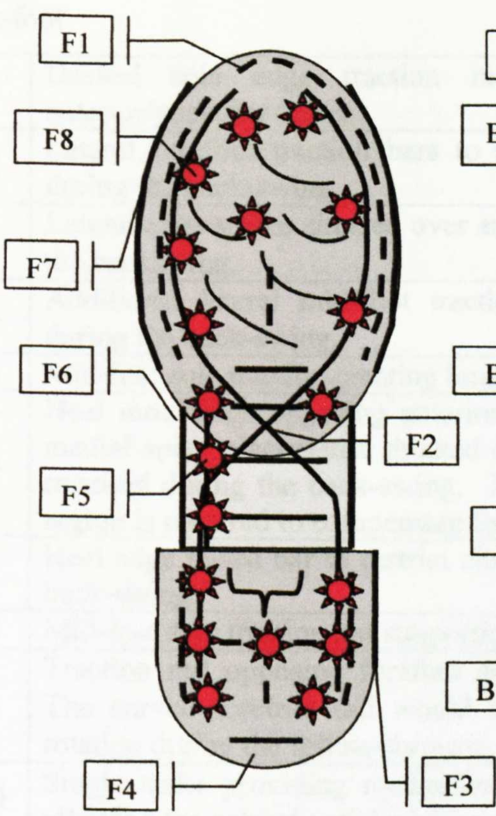


Figure 7.3 Front (left) Foot Shoe Sole Interface Recommendations.

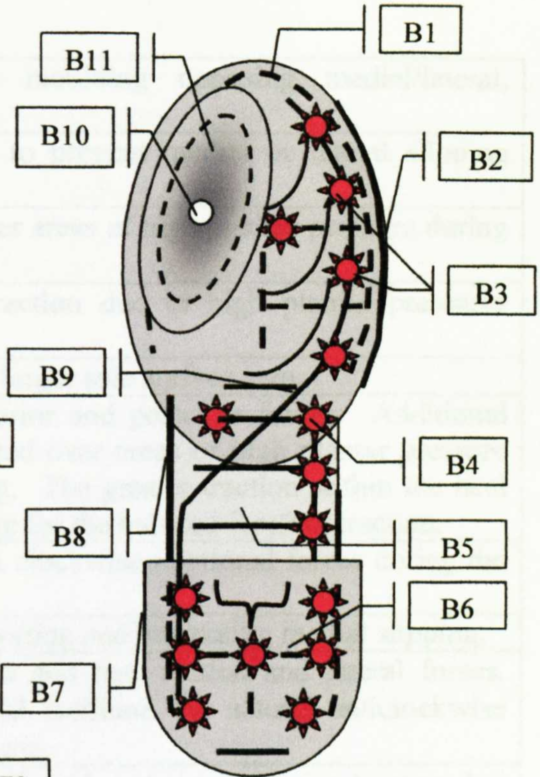


Figure 7.4 Back (right) Foot Shoe Sole Interface Recommendations.

Key
= Spike position
F = Front-foot
B = Back-foot

Front-foot

F1	Dashed sole edge traction moulding opposing medial/lateral, anterior/posterior forces
F2	Traction rail(s) opposing forefoot and heel medial and lateral forces
F3	Heel edge raised bar to restrict anticlockwise rotational forces during the follow through.
F4	Heel mouldings opposing anterior and posterior forces. Additional lateral spike placements situated over areas of high plantar pressure during the downswing and follow-through
F5	Additional lateral mid-foot traction due to high plantar pressures during the downswing and follow-though swing stages.
F6	Mid-foot sole traction bar supporting and preventing lateral slipping.
F7	Lateral forefoot traction bars to prevent medial or lateral slipping during the downswing and follow-through
F8	Lateral edge spikes situated over areas of high in-shoe pressure during the downswing and follow-through.

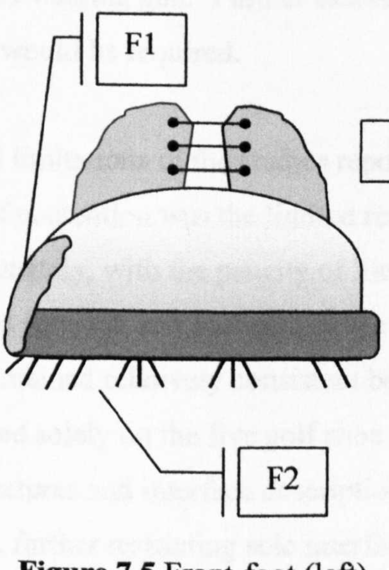
Table 7.1 Front-foot Shoe Sole Interface Descriptions (Figure 7.3).

Back-foot

B1	Dashed sole edge traction moulding opposing medial/lateral, anterior/posterior forces
B2	Lateral forefoot traction bars to prevent medial or lateral slipping during the back-swing
B3	Lateral edge spikes situated over areas of high in-shoe pressure during the backswing.
B4	Additional lateral mid-foot traction due to high plantar pressures during the back-swing.
B5	Mid-foot sole traction creating larger sole surface area.
B6	Heel mouldings opposing anterior and posterior forces. Additional medial spike placements situated over areas of high plantar pressure required during the back-swing. The greater traction within the heel region is required to compensate for the reduced forefoot traction.
B7	Heel edge raised bar to restrict clockwise rotational forces during the back-swing.
B8	Mid-foot sole traction bar supporting and preventing medial slipping.
B9	Traction rail opposing forefoot and heel medial and lateral forces. The curved forefoot rail would facilitate the natural anticlockwise rotation during the follow-through.
B10	Single spike providing medial/lateral, anterior/posterior traction but allowing the natural anticlockwise rotation during the follow-through.
B11	Raised sole oval area to facilitate the natural forefoot rotation anticlockwise rotation during the follow-through. Raised traction mouldings on the oval border to maintain forefoot placement during the anticlockwise rotations. The limited forefoot traction facilitates the natural anticlockwise rotations during the follow-through.

Table 7.2 Back-foot Shoe Sole Interface Descriptions (Figure 7.4).

Figures 7.5 and 7.6 illustrative recommendations for the front of the front and back shoes



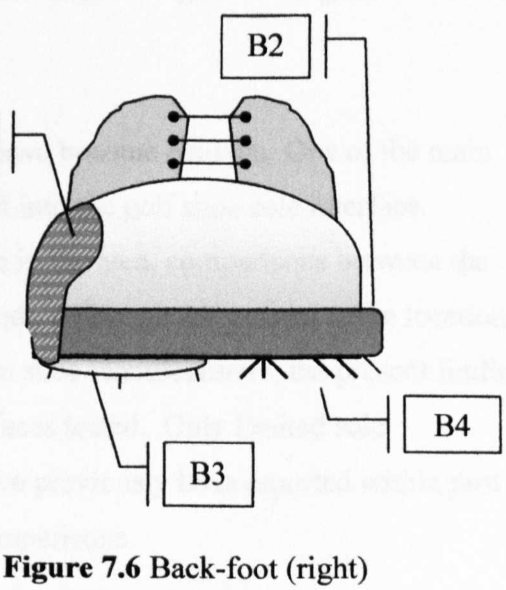


Figure 7.5 Front-foot (left) Front View Sole Development Recommendations.

Figure 7.6 Back-foot (right) Front View Sole Development Recommendations.

Front-foot

F1	Wider supported lateral sole edge providing shoe support and preventing the shoe buckling during the downswing and follow-through.
F2	Angled spikes opposing the medial/lateral and anterior/posterior forces. More spikes located on the lateral edge to provided traction during the downswing and follow-through.

Table 7.3 Front-foot Shoe Sole Interface Descriptions (Figure 7.5).

Back-foot

B1	Medial forefoot moulding to facilitate forefoot anticlockwise rotation onto the toe during the follow-through. The moulding incorporates traction groves to provided stability during this stage of the swing process.
B2	Wider lateral sole edge providing shoe support during the backswing.
B3	Medial forefoot raised oval moulding allowing the natural anticlockwise rotation of the forefoot during the follow-through. The moulding incorporates a single spike to stabilise the forefoot position. Mouldings surrounding the oval moulding prevent any linear slipping during the rotational movement.
B4	Angled spikes opposing the medial/lateral and anterior/posterior forces. More spikes located on the lateral edge to provided traction during the backswing.

Table 7.4 Back-foot Shoe Sole Interface Descriptions (Figure 7.6).

Future research into a developmental shoe sole interface based on the thesis recommendations is required. The functional performance of the recommended sole design needs to be assessed using dynamic measures as identified within chapter 5 and 6. It is also not clear how an asymmetrical sole interface design would influence a golfers walking gait. Further assessment during prolonged walking over differing terrain would be required.

Several limitations of the studies reported have become evident. One of the main areas of contention was the limited research into the golf shoe sole interface. Unfortunately, with the paucity of literature in the area, comparisons between the reported research and past studies are limited. Although the general spike locations have remained relatively consistent between shoe manufacturers, the present findings are based solely on the five golf shoe interfaces tested. Only limited sole manufactures and interface descriptions have previously been reported within past studies, further restricting sole interface comparisons.

However, the limitations of the reported studies provide impetus for further research in the area. As identified within the limited previous research the findings from chapters 2, 5 and 6 assessed dynamic golf swing movements of male golfers. Research directed towards the analysis of dynamic forces and movements of female golfers and their influences on sole interface design has yet to be quantified.

The thesis demonstrated the application of biomechanics in the evaluation of shoe-design can provide important results. Future research might focus towards the development and evaluation of a front and back-foot shoe sole interface design based on the thesis's findings and recommendations. Analysis of the interaction between the golf shoe sole interface and the grass surface and the interaction between the golfer and shoe were identified. Further analysis identifying the differences within golfing performance e.g. shot length and consistency between sole interface designs would further enhance the current findings. The thesis only identified sole interface tractional properties on horizontal grass. Different terrain, grass types, ground surface angles and grass moisture levels would further enhance the present sole interface performance characteristics findings.

7.2: CONCLUSIONS

The investigation into the interactions between the golfer and the shoe sole in conjunction with the shoe sole interaction with the ground has revealed several novel findings, which aid our understanding of golf shoe sole interface requirements and design. Initially, research centred on kinematic analysis of the lower limb and foot actions during the golf swing and established generic movements across a golfing population. Possible limitations within the golf shoe sole interface traction during the swing process were identified. Mechanical traction testing of five different golf shoe sole interface designs highlighted variations between sole interfaces when golf swing specific linear and rotational forces were applied. Chapter 5 identified the interaction between the golf shoe interface and the ground. The study investigated the ground action force differences between shoe sole interfaces during the golf swing process. The findings confounded those identified within the previous mechanical traction tests. The study concluded that when dynamic forces were applied to the shoe during the golf swing limited ground action force differences were identified between sole interface conditions. The study raised concerns regarding the functional purpose of traditional and modern golf shoe traction. No ground action force differences were identified between handicap groups, suggesting a universal sole interface design could be used between different skill levels. Although unrelated to sole interface design, significant slower weight transfer times were identified within the low handicap group. The slower weight transfer times allowed a more controlled swing, providing golfers and coaches with an understanding for improved golfing performance. Analysis of the interaction between the golfer and the shoe was gained through in-shoe plantar pressure insoles. Regional in-shoe analysis identified pressure locations during the swing process to be greater within the front shoe. The asymmetrical demands placed upon the shoes support the previous ground action force measurements. In-shoe analysis revealed no shoe sole interface to provide consistently higher traction when compared to the flat-soled shoe raising further sole interface concerns. From the thesis findings, shoe sole recommendations were identified from the researched shoe sole interface designs within the thesis.

Such dynamic ground action force and in-shoe planter pressure methods of footwear assessment can provide useful data to manufactures and clinicians concerning the potential of sole interface design for effective traction during sports specific situations.

In conclusion, the research detailed within this thesis provided new evidence concerning the evaluation of the golf shoe sole interface on a natural grass surface. The thesis emphasised the importance of dynamic golf shoe sole testing using human subjects on natural turf surface. Traditional and modern shoe sole interface designs were unable to consistently provide the golfer with the traction and natural movements required during the swing process. As a consequence within the dynamic analysis they performed comparably to a flat-soled interface. In-shoe analysis identified regional locations, which require increased and altered sole interface traction to create a golf shoe specifically designed for the golf swing process. At present, golf shoe sole interfaces do not provide the traction or facilitate the movements required by the golfer during the swing process.

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APPENDIX A

(Relevant to Chapter 2)

FOOT MOVEMENT PATTERNS DURING THE GOLF SWING

INFORMED CONSENT FORM:

For the research you will be required to play a single golf shot using your own selected club in your own golf shoes. Shots will be played from the 1st tee. Shots will be recorded using two separate cameras and used for subsequent analysis. Shoe sole type and make, handicap, age, height and mass will be recorded. Observational notes will also be taken from your swing technique.

I (print name and date) .... hereby give my consent to participate in the testing explained to me. I am satisfied that I understand the procedures involved and accept the possible injury risks involved in the testing. I understand that I may withdraw from the experiment at anytime without reason.

Subjects full signature: ....

Experimenters signature: ....

Date:...

APPENDIX B

(Relevant to Chapter 4)

Anti-clockwise Rotation Results

yfzmin	bfzmin	gfzmin	rfzmin	blfzmin	yfzmax	bfzmax	gfzmax	rfzmax
299.44	322.93	308.64	320.06	326.46	353.3	351.16	351.53	360.75
304.73	321.61	304.12	310.2	327.03	354.49	357.49	367.67	348.6
313.27	324.6	290.16	316.27	319.9	342.69	349.91	356.95	365.8
303.72	281.39	311.1	308.15	313.38	346.77	341.48	350.85	358.07
279.83	280.44	303.5	287.29	317.2	330.3	346.21	356.75	341.07
300.2	299.87	310.47	308.4	325.86	345.51	345.53	358.06	354.86
300.35	305.14	301.75	298.06	321.64	343.95	348.63	364.12	353.68
299.47	302.18	314.26	275.23	315.83	341.84	348.21	355.33	354.7

blfzmax	ytzmin	btzmin	gtzmin	rtzmin	bltzmin	ytzmax	btzmax	gtzmax	rtzmax	bltzmax
348.3	-14.45	-14.88	-28.47	-15.18	-8.35	4.3	1.44	0.44	3.13	1.56
348.08	-14.29	-12.31	-24.1	-13.78	-7.04	2.31	2.45	0.12	0.97	2.34
348.13	-11.12	-12.85	-20.11	-29.27	-9.35	2.06	1.01	2.28	-1.82	4.31
347.37	-12.58	-15.35	-18.84	-13.59	-8.4	1.34	1.35	1.05	4.88	2.75
340.38	-14.59	-13.69	-22.88	-11.27	-6.54	1.12	3.13	0.26	2.27	3.32
347.63	-13.41	-12.17	-21.48	-16.62	-6.66	2.23	3.47	0.21	1.89	2.6
346.65	-13.2	-13.54	-20.83	-16.9	-7.72	1.81	2.14	0.95	1.64	2.81
338.37	-12.98	-13.32	-21.01	-17.53	-8.62	1.71	2.26	0.62	1.77	3.02

Key
b = Blue Shoe
g = Green Shoe
y = Yellow Shoe
bk = Black Shoe
r = Red Shoe

Clockwise Rotation Results

yfzmin	bfzmin	gfzmin	rfzmin	blfzmin	yfzmax	bfzmax	gfzmax	rfzmax
298.4	307.68	314.26	325.74	329.55	337.99	353.5	353.93	359.25
309.47	322.09	317.68	320.05	335.04	355.52	363.02	355.37	365.24
311.33	319.23	326.83	316.19	323.69	357.3	368.12	367.99	377.7
294.68	319.9	308.02	319.39	328.44	350.98	354.36	346.9	353.93
297.71	317.23	307.48	325	323.39	347.86	359.75	351.17	358.75
328.53	319.61	314.86	327.99	332.4	351.95	361.31	355.07	360.16
306.68	318.99	319.97	322.39	328.75	350.27	360.89	358.3	362.51
308.07	318.93	316.43	321.84	328.62	352.31	359.08	365.29	363.05

blfzmax	ytzmin	btzmin	gtzmin	rtzmin	bltzmin	ytzmax	btzmax	gtzmax	rtzmax	bltzmax
353.45	-3.61	-2.41	-2.41	-1.93	-2.35	12.51	18.7	18.2	12.93	9.6
355.78	-1.4	-2.73	-7.92	-4.06	-3.96	14.54	17.16	13.6	14.82	8.32
348.13	-1.57	-7.53	-2.89	-4.23	-1.48	14.39	10.42	13.3	12.66	8.99
349.57	-1.22	-0.18	-0.86	-2.84	-2.6	15.81	17.46	15.43	10.42	7.21
359.66	-1.83	-3.21	-1.02	-2.07	-2.76	11.8	15.93	22.86	13.84	7.37
352.59	-2.36	-3.41	-3.02	-3.87	-2.77	15.31	15.24	16.68	16.07	6.55
353.2	-2	-3.58	-3.14	-3.17	-2.66	14.06	14.76	16.37	13.46	8.01
343.16	-1.73	-2.6	-2.19	-3.37	-2.71	14.32	15.85	16.93	13.54	7.74

Key
b = Blue Shoe
g = Green Shoe
y = Yellow Shoe
bk = Black Shoe
r = Red Shoe

Limiting Factor Results

ycl	bcl	gcl	rcl	blcl	yanticl	banticl	ganticl	ranticl
0.05	0.05	0.07	0.04	0.01	-0.05	-0.03	-0.06	0.01
0.05	0.03	0.04	0.03	0.02	-0.04	-0.03	-0.07	0.01
0.04	0.05	0.04	0.03	0	-0.03	-0.04	-0.06	-0.01
0.05	0.05	0.04	0.04	0.01	-0.03	-0.05	1	0
0.04	0.04	0.05	0.05	0.01	-0.04	-0.04	1	-0.04
0.04	0.04	0.05	0.04	0.01	-0.04	-0.02	0.37	-0.01
0.04	0.04	0.04	0.04	0.01	-0.04	-0.03	0.45	-0.01
0.04	0.04	0.04	0.04	0.01	-0.04	-0.03	0.56	-0.01

blanticl	yff	bff	gff	rff	blff	ywf	bwf	gwf	rwf	blwf
-0.02	-1.16	-0.45	-0.72	-0.43	-0.28	1.13	0.72	1.02	0.89	0.58
-0.02	-1.1	-0.45	-1	-0.41	-0.29	1.25	0.47	0.92	1.2	0.58
-0.02	-0.91	-0.43	-0.84	-0.75	-0.23	0.91	0.48	1.02	0.52	0.52
-0.01	-0.87	-0.46	-0.99	-0.86	-0.47	1.04	0.8	1.09	1.01	0.5
-0.02	-0.94	-0.41	-0.98	-0.95	-0.54	0.99	0.79	1.05	1.11	0.48
-0.02	-0.99	-0.47	-0.69	-1.32	-0.35	1.11	0.76	1.06	0.95	0.67
-0.02	-0.99	-0.43	-0.76	-0.78	-0.36	1.06	0.75	1.07	0.95	0.55
-0.02	-0.97	-0.44	-0.89	-0.84	-0.37	1.04	0.65	1.09	0.96	0.54

Key

b = Blue Shoe   ff = Fore-foot
g = Green Shoe   wf = Whole-foot
y = Yellow Shoe
bk = Black Shoe
r = Red Shoe

Linear Forefoot Results

yfymin	bfymin	gfymin	rfymin	bkfymin	yfymax	bfymax	gfymax	rfymax
-327.82	-321.01	-388.03	-365.48	-297.06	-22.25	-27.8	-29.13	-50.52
-314.4	-367.99	-465.55	-379.83	-300.98	-30.89	-26.07	-13.2	-49.81
-381.59	-323.82	-341.11	-316.28	-273.29	-30.6	-8.14	-11.02	-25.32
-360.84	-328.52	-414.17	-392.24	-307.33	-28.97	-18.09	-17	-28.14
-310.09	-363.8	-513.96	-340.75	-290.85	-28.74	-38.71	-14.68	-13.7
-338.95	-348.05	-373.24	-409.99	-283.86	-28.29	-2.47	-14.25	-51.83
-341.17	-342.2	-416.01	-367.43	-292.23	-29.5	-28.2	-16.55	-36.55
-346.53	-345.73	-420.67	-347.75	-291.42	-29.22	-20.28	-14.45	-34.23

blfymax	yfzmin	bfzmin	gfzmin	rfzmin	blfzmin	yfzmax	bfzmax	gfzmax	rfzmax	blfzmax
-59.81	220.65	250.04	250.48	144.04	199.34	380.96	361.78	379.18	357.67	362.81
-61.92	199.12	243.01	247.63	209.67	111.34	379.39	358.53	385.63	361.39	363.85
-64.59	186.64	235.84	243.22	275.44	124.73	372.83	371.79	385.96	373.62	361.38
-52.2	219.87	227.02	258.94	167.89	160.35	382.32	367.39	391.89	362.35	374.44
-59.22	206.08	191.97	246.44	221.17	140.36	377.44	366.96	314.14	367.69	367.7
-66.99	206.47	249.69	238.59	134.86	94.17	378.59	381.23	366.89	356.37	360.08
-60.79	203.64	232.93	247.55	192.18	138.38	378.11	367.95	370.62	363.18	365.05
-60.95	204.54	230.08	247.06	180.2	128.22	377.86	368.98	369.19	364.1	365.42

Key
b = Blue Shoe
g = Green Shoe
y = Yellow Shoe
bk = Black Shoe
r = Red Shoe

Linear Whole-Foot Results

yfymin	bfymin	gfymin	rfymin	blfymin	yfymax	bfymax	gfymax	rfymax
-343.07	-360.5	-311.5	-338.31	-269.71	39.47	30.6	70.21	57.37
-385.5	-346.28	-415.37	-364.2	-305.9	38.52	36.98	37.63	56.59
-349.29	-387.33	-388.04	-353.64	-293.35	50.85	19.1	27.12	47.64
-345	-403.46	-419.95	-351.27	-308.79	52.27	17.26	41.56	38.31
-378.33	-340.47	-383.72	-366.48	-274.24	24.25	37.27	44.13	65.27
-351.6	-367.61	-401.77	-354.78	-316.81	41.07	17.64	37.61	54.01
-325.17	-369.03	-398.37	-328.07	-294.8	48.39	26.89	37.6	43.2
-353.99	-373.58	-400.95	-346.85	-298.98	36.97	26.53	40.22	52.5

blfymax	yfzmin	bfzmin	gfzmin	rfzmin	blfzmin	yfzmax	bfzmax	gfzmax	rfzmax	blfzmax
19.13	263.21	249.03	249.65	198.36	148.99	353.03	355.96	363.52	350.95	350.79
15.36	174.98	249.25	253.54	239.74	188.57	514.78	363.91	394.38	348.49	355.6
27.32	218.67	194.97	238.68	196.16	214.41	355.41	478.23	359.25	355.46	358.8
15.42	230.45	192.25	233.8	261.37	212.47	350	454.77	349.4	363.81	359.46
12.71	128.01	240.89	243.92	267.39	208.73	506.84	362.02	366.64	350.35	346.65
17.99	177.04	225.28	242.48	232.61	186.97	415.91	402.98	367.42	353.81	349.26
17.76	199.58	220.53	239.72	229.46	193.36	390.49	412.38	360.68	334.38	353.43
18.24	198.85	214.78	239.98	239.4	200.75	412.35	422.07	361.04	345.56	342.87

Key
b = Blue Shoe
g = Green Shoe
y = Yellow Shoe
bk = Black Shoe
r = Red Shoe

APPENDIX C

(Relevant to Chapter 5)

Performance Characteristics of Modern Golf Shoe Sole and Spike Designs

Informed Consent Form:

For the research you will be required to play approximately 100 golf shots using three different clubs in various types of golfing footwear (provided by the university). Shots will be played off a driving matt (either directly or off tee pegs) into golf netting. Shots will be recorded using two separate cameras and weight / foot movement patterns will be collected and analysed via force platforms set in grass. The research will not be assessing shot performance, only weight and movement patterns.

I (print name and date) .... hereby give my consent to participate in the testing explained to me. I am satisfied that I understand the procedures involved and accept the possible injury risks involved in the testing. I understand that I may withdraw from the experiment at anytime without reason.

Subjects full signature: ....

Experimenters signature: ....

Date: ....

APPENDIX D

(Relevant to Chapter 5)

DRIVER

(Relevant to Chapter 5)

Blue Handicap	Driver Ball impact Time (s)	Blue Weight Traf Time (s)	Blue FF Fx Range (BW)	Blue FF Fy Range (BW)	Blue FF Fz max value (BW)	Blue FF Fz Range (BW)	Blue FF Fz max time (s)	Blue FF Mz max value (N.m)
1	1.530	1.538	0.211	0.202	0.756	0.760	3.070	13.136
2	1.080	0.210	0.330	0.278	0.794	0.788	2.198	29.371
1	1.340	1.430	0.216	0.241	0.624	0.626	3.178	11.310
2	1.860	0.178	0.247	0.370	0.981	0.982	1.935	12.052
2	1.230	0.537	0.228	0.297	0.701	0.697	2.325	28.153
1	2.050	0.107	0.204	0.283	0.875	0.868	1.962	16.887
3	1.670	0.140	0.405	0.266	0.856	0.851	2.153	25.173
3	0.330	0.031	0.284	0.273	1.013	1.011	1.107	28.125
3	1.070	0.864	0.251	0.271	1.058	1.056	2.040	16.900
2	1.760				.			.
3	0.910	0.435	0.226	0.446	0.948	0.940	1.504	23.979
1	2.570	0.792	0.265	0.289	0.839	0.834	3.408	21.184
1	2.540	0.745	0.259	0.256	0.794	0.778	3.227	27.907
1	6.990	0.058	0.331	0.308	0.797	0.806	1.998	25.266
2	1.370	0.935	0.234	0.350	0.760	0.748	3.047	15.679
2	1.130	0.954	0.307	0.255	0.788	0.781	2.234	24.177
3	1.910	0.983	0.274	0.365	0.680	0.692	3.139	14.926
3	0.480	0.134	0.230	0.375	0.828	0.808	1.854	21.633
1	.				.		.	.
3	.				.			.
2	1.443	0.483	0.222	0.269	0.662	0.661	2.251	19.731
3	1.607	0.561	0.268	0.366	0.934	0.930	2.088	17.639
2	1.823	0.156	0.299	0.284	0.798	0.794	2.295	24.837
1	1.640	0.248	0.249	0.271	0.894	0.886	2.053	24.306
TOTAL								
MEAN	**1.742**	**0.549**	**0.264**	**0.301**	**0.828**	**0.824**	**2.337**	**21.065**
SD	1.296	0.197	0.049	0.057	0.115	0.114	0.612	5.692
SE	0.265	0.040	0.010	0.012	0.024	0.023	0.125	1.162
	Low Handicap							
Mean	**2.666**	**0.703**	**0.248**	**0.264**	**0.797**	**0.794**	**2.700**	**19.999**
SD	1.967	0.259	0.044	0.035	0.090	0.087	0.658	6.358
SE	0.695	0.092	0.016	0.012	0.032	0.031	0.233	2.248
	Medium Handicap							
Mean	**1.462**	**0.493**	**0.267**	**0.300**	**0.783**	**0.779**	**2.326**	**22.000**
SD	0.315	0.050	0.044	0.043	0.101	0.103	0.343	6.443
SE	0.112	0.018	0.016	0.015	0.036	0.036	0.121	2.278
	High Handicap							
Mean	**1.140**	**0.450**	**0.277**	**0.338**	**0.902**	**0.898**	**1.984**	**21.196**
SD	0.611	0.183	0.060	0.069	0.127	0.125	0.632	4.868
SE	0.216	0.065	0.021	0.024	0.045	0.044	0.223	1.721

Green Handicap	Driver Ball impact Time (s)	Green Weight Traf Time (s)	Green FF Fx Range (BW)	Green BF Fy Range (BW)	Green FF Fz max value (BW)	Green FF Fz Range (BW)	Green FF Fz max time (s)	Green FF Mz max value (N.m)
	1.390	0.531	0.227	0.212	0.762	0.762	2.113	12.769
	1.040	-0.165	0.235	0.287	0.925	0.918	2.126	20.675
	1.280	1.425	0.210	0.232	0.630	0.634	3.229	9.728
	1.930	0.035	0.174	0.343	0.976	0.978	1.845	9.815
	0.960	0.947	0.268	0.282	0.703	0.697	2.404	24.648
	1.620	0.894	0.206	0.272	0.870	0.863	2.838	18.128
	1.830	0.630	0.275	0.262	0.852	0.846	3.040	23.039
	8.830	0.052	0.264	0.273	0.981	0.981	0.956	27.993
	0.970	0.083	0.270	0.292	1.090	1.080	1.080	15.738
	1.980	0.222	0.271	0.237	0.695	0.687	2.576	19.846
	0.890	0.417	0.235	0.424	0.935	0.925	1.293	24.760
	2.480	0.859	0.255	0.305	0.856	0.849	3.420	19.545
	2.200	0.063	0.269	0.273	0.820	0.803	2.237	29.056
	5.310	1.112	0.359	0.325	0.795	0.806	3.082	28.121
	1.440	1.139	0.237	0.362	0.809	0.796	3.058	23.321
	1.270	0.905	0.271	0.277	0.797	0.788	2.168	27.689
	1.800	0.393	0.279	0.338	0.826	0.838	2.127	29.479
	0.510	1.005	0.240	0.361	0.857	0.847	1.885	6.332
	0.000	0.237	0.298	0.323	0.721	0.698	1.182	26.041
	0.990							
	1.407	0.532	0.231	0.251	0.676	0.673	2.403	18.074
	1.480	0.449	0.205	0.346	0.927	0.922	1.992	17.568
	1.757	0.145	0.266	0.283	0.804	0.797	2.288	22.411
	4.217	0.336	0.246	0.273	0.890	0.882	2.010	25.059
TOTAL								
MEAN	**1.983**	**0.532**	**0.252**	**0.297**	**0.835**	**0.829**	**2.233**	**20.862**
SD	1.829	0.164	0.038	0.049	0.110	0.110	0.686	6.594
SE	0.373	0.033	0.008	0.010	0.022	0.022	0.140	1.346
	Low Handicap							
Mean	**2.312**	**0.682**	**0.259**	**0.277**	**0.793**	**0.787**	**2.514**	**21.056**
SD	1.707	0.287	0.051	0.040	0.087	0.086	0.758	7.198
SE	0.603	0.101	0.018	0.014	0.031	0.030	0.268	2.545
	Medium Handicap							
Mean	**1.473**	**0.470**	**0.244**	**0.290**	**0.798**	**0.792**	**2.358**	**20.810**
SD	0.386	0.024	0.033	0.042	0.108	0.110	0.359	5.348
SE	0.137	0.009	0.012	0.015	0.038	0.039	0.127	1.891
	High Handicap							
Mean	**2.163**	**0.433**	**0.253**	**0.328**	**0.924**	**0.920**	**1.768**	**20.701**
SD	2.734	0.139	0.027	0.057	0.092	0.088	0.727	8.094
SE	0.966	0.049	0.010	0.020	0.032	0.031	0.257	2.862

Red Handicap	Driver Ball impact Time (s)	Red Weight Traf Time (s)	Red FF Fx Range (BW)	Red BF Fy Range (BW)	Red FF Fz max value (BW)	Red FF Fz Range (BW)	Red FF Fz max time (s)	Red FF Mz max value (N.m)
	1.570	1.320	0.212	0.226	0.761	0.764	2.851	26.733
	1.200	0.469	0.231	0.208	0.665	0.669	2.286	19.576
	1.410	0.631	0.253	0.287	0.649	0.657	2.232	16.541
	1.690	0.367	0.194	0.388	0.960	0.963	1.875	12.463
	0.880	1.054	0.218	0.312	0.791	0.792	2.300	11.403
	1.740	0.748	0.199	0.293	0.873	0.868	2.835	14.879
	1.590	0.858	0.344	0.254	0.897	0.892	3.119	19.826
	8.620	0.122	0.233	0.304	0.987	0.989	0.951	22.607
	1.110	0.342	0.314	0.311	1.394	1.384	1.922	17.602
	1.760	0.186	0.258	0.239	0.672	0.667	2.528	20.599
	0.840	-0.475	0.226	0.436	0.958	0.952	1.400	22.124
	2.650	0.241	0.263	0.300	0.746	0.741	2.559	20.304
	2.400	0.573	0.251	0.309	0.943	0.936	2.352	20.157
	6.130	0.719	0.330	0.315	0.817	0.829	3.000	19.585
	1.370	0.286	0.256	0.323	0.750	0.736	2.101	20.753
	1.220	1.001	0.294	0.199	0.822	0.820	3.014	20.652
	1.540	0.903	0.281	0.322	0.818	0.825	2.098	16.025
	0.630	0.540	0.227	0.366	0.866	0.854	1.731	12.793
	1.820	0.930	0.297	0.341	0.775	0.755	2.266	21.330
	0.790	0.491	0.243	0.280	1.001	0.993	2.882	16.980
	1.350	0.624	0.224	0.280	0.704	0.705	2.353	25.181
	1.423	0.547	0.206	0.372	0.931	0.928	2.037	16.488
	1.707	-0.168	0.275	0.289	0.811	0.808	2.326	19.844
	4.253	0.481	0.227	0.306	0.934	0.931	2.046	19.881
TOTAL								
MEAN	**2.071**	**0.533**	**0.252**	**0.303**	**0.855**	**0.852**	**2.294**	**18.930**
SD	1.827	0.076	0.041	0.055	0.155	0.154	0.520	3.751
SE	0.373	0.015	0.008	0.011	0.032	0.031	0.106	0.766
	Low Handicap							
Mean	**2.747**	**0.705**	**0.254**	**0.297**	**0.812**	**0.810**	**2.517**	**19.926**
SD	1.643	0.024	0.044	0.033	0.101	0.098	0.347	3.496
SE	0.581	0.009	0.015	0.012	0.036	0.035	0.123	1.236
	Medium Handicap							
Mean	**1.397**	**0.477**	**0.244**	**0.280**	**0.772**	**0.770**	**2.348**	**18.809**
SD	0.306	0.079	0.033	0.063	0.097	0.098	0.331	4.595
SE	0.108	0.028	0.012	0.022	0.034	0.035	0.117	1.624
	High Handicap							
Mean	**2.068**	**0.416**	**0.259**	**0.331**	**0.981**	**0.977**	**2.017**	**18.056**
SD	2.672	0.170	0.049	0.058	0.178	0.175	0.715	3.296
SE	0.945	0.060	0.017	0.020	0.063	0.062	0.253	1.165

Black Handicap	Driver Ball impact Time (s)	Black Weight Traf Time (s)	Black FF Fx Range (BW)	Black BF Fy Range (BW)	Black FF Fz max value (BW)	Black FF Fz Range (BW)	Black FF Fz max time (s)	Black FF Mz max value (N.m)
	1.560	1.493	0.194	0.193	0.756	0.759	2.891	14.640
	1.120	0.927	0.242	0.379	0.866	0.858	2.225	19.635
	1.520	1.452	0.223	0.280	0.680	0.687	3.122	22.995
	2.200	0.839	0.247	0.335	0.964	0.967	2.914	10.721
	0.970	0.860	0.255	0.284	0.743	0.738	2.316	20.257
	1.650	0.308	0.209	0.273	0.844	0.838	2.898	12.316
	1.980	0.308	0.349	0.244	0.819	0.818	3.056	19.094
	0.720	0.067	0.284	0.278	1.007	1.006	1.063	25.991
	1.040	0.455	0.294	0.292	1.202	1.195	2.005	20.258
	1.760	0.398	0.224	0.233	0.631	0.630	2.507	21.157
	6.840	0.326	0.221	0.454	0.930	0.924	1.424	16.882
	2.870	0.993	0.285	0.295	0.775	0.769	3.399	21.952
	2.860	0.308	0.270	0.274	0.819	0.807	3.264	21.827
	7.200	0.771	0.291	0.319	0.809	0.815	3.071	18.518
	1.490	0.323	0.240	0.381	0.778	0.768	2.288	23.350
	1.170	0.026	0.265	0.254	0.783	0.776	1.201	20.015
	1.680	0.776	0.304	0.310	0.797	0.803	2.176	17.386
	0.610	0.645	0.248	0.357	0.774	0.764	1.868	12.413
	1.300	0.012	0.288	0.342	0.727	0.707	1.189	21.137
	1.090	0.320	0.224	0.314	1.066	1.063	2.727	15.810
	2.082	0.295	0.257	0.304	0.838	0.835	2.120	18.018
	2.108	0.285	0.260	0.310	0.842	0.838	2.132	18.187
	2.157	0.253	0.261	0.307	0.841	0.837	2.127	18.114
	2.189	0.243	0.263	0.308	0.849	0.845	2.127	18.370
TOTAL								
MEAN	**2.090**	**0.528**	**0.258**	**0.305**	**0.839**	**0.835**	**2.338**	**18.710**
SD	1.631	0.118	0.035	0.054	0.124	0.124	0.673	3.660
SE	0.333	0.024	0.007	0.011	0.025	0.025	0.137	0.747
	Low Handicap							
Mean	**2.644**	**0.697**	**0.253**	**0.286**	**0.782**	**0.778**	**2.745**	**18.969**
SD	1.938	0.120	0.039	0.044	0.059	0.059	0.736	3.809
SE	0.685	0.042	0.014	0.016	0.021	0.021	0.260	1.347
	Medium Handicap							
Mean	**1.619**	**0.490**	**0.249**	**0.310**	**0.805**	**0.801**	**2.212**	**18.908**
SD	0.500	0.121	0.014	0.054	0.098	0.099	0.483	3.719
SE	0.177	0.043	0.005	0.019	0.035	0.035	0.171	1.315
	High Handicap							
Mean	**2.008**	**0.398**	**0.273**	**0.320**	**0.930**	**0.926**	**2.056**	**18.252**
SD	2.030	0.010	0.043	0.063	0.151	0.150	0.643	3.915
SE	0.718	0.003	0.015	0.022	0.054	0.053	0.227	1.384

Yellow Handicap	Driver Ball impact Time (s)	Yellow Weight Traf Time (s)	Yellow FF Fx Range (BW)	Yellow BF Fy Range (BW)	Yellow FF Fz max value (BW)	Yellow FF Fz Range (BW)	Yellow FF Fz max time (s)	Yellow FF Mz max value (N.m)
	1.170	0.837	0.235	0.198	0.767	0.771	2.113	13.352
	1.000	0.864	0.281	0.304	0.891	0.878	2.298	36.666
	1.700	0.344	0.249	0.267	0.685	0.694	2.236	19.077
	2.020	0.838	0.188	0.366	0.973	0.975	2.850	14.071
	1.080	0.018	0.283	0.282	0.728	0.720	1.424	24.581
	1.990	1.630	0.207	0.274	0.846	0.840	3.840	13.956
	1.730	0.729	0.321	0.275	0.873	0.867	3.095	19.043
	0.590	0.132	0.252	0.310	0.989	0.989	1.074	35.302
	1.100	0.509	0.336	0.265	1.120	1.114	1.639	17.358
	1.690	0.385	0.256	0.252	0.654	0.646	2.441	19.255
	7.860	0.449	0.241	0.437	0.929	0.920	1.474	17.572
	2.840	0.475	0.283	0.302	0.810	0.802	2.563	26.473
	2.570	0.525	0.269	0.298	0.848	0.833	3.210	29.720
	1.720	0.184	0.273	0.331	0.810	0.819	1.957	23.117
	1.530	0.331	0.253	0.337	0.740	0.726	2.070	20.201
	1.270	0.749	0.275	0.267	0.772	0.767	2.217	20.010
	1.970	0.428	0.247	0.348	0.746	0.754	2.545	22.250
	0.410	0.871	0.224	0.341	0.832	0.818	1.889	16.116
	1.820							
	0.000	0.590	0.282	0.311	0.927	0.924	2.938	14.953
	1.803	0.405	0.259	0.303	0.839	0.835	2.140	21.214
	1.835	0.082	0.260	0.309	0.843	0.838	2.142	21.628
	1.876	0.356	0.259	0.309	0.840	0.836	2.134	20.837
	1.885	0.957	0.260	0.312	0.848	0.843	2.528	20.929
TOTAL								
MEAN	**1.811**	**0.552**	**0.261**	**0.304**	**0.840**	**0.835**	**2.296**	**21.204**
SD	1.438	0.148	0.032	0.046	0.104	0.104	0.625	6.135
SE	0.294	0.030	0.007	0.009	0.021	0.021	0.128	1.252
	Low Handicap							
Mean	**1.962**	**0.707**	**0.254**	**0.283**	**0.802**	**0.800**	**2.635**	**20.946**
SD	0.524	0.212	0.026	0.043	0.060	0.053	0.670	6.086
SE	0.185	0.075	0.009	0.015	0.021	0.019	0.237	2.152
	Medium Handicap							
Mean	**1.534**	**0.493**	**0.257**	**0.303**	**0.805**	**0.798**	**2.197**	**22.104**
SD	0.380	0.148	0.030	0.037	0.102	0.104	0.399	6.560
SE	0.134	0.052	0.011	0.013	0.036	0.037	0.141	2.319
	High Handicap							
Mean	**1.937**	**0.474**	**0.270**	**0.325**	**0.907**	**0.903**	**2.099**	**20.528**
SD	2.500	0.068	0.040	0.054	0.113	0.112	0.717	6.481
SE	0.884	0.024	0.014	0.019	0.040	0.040	0.253	2.291

Blue FF Mz range (N.m)	Blue FF Mz max time (s)	Blue FF Tz max value (N.m)	Blue FF Tz Range (N.m)	Blue FF COFxy max	Blue BF Fx Range (BW)	Blue BF Fy Range (BW)	Blue BF Fz max value (BW)	Blue BF Fz Range (BW)	Blue BF Fz max time (s)
37.038	1.345	19.785	37.06	0.512	0.196	0.128	0.558	0.362	1.533
58.182	1.774	12.274	38.98	0.676	0.223	0.185	0.482	0.391	1.988
26.566	1.513	12.216	24.30	0.758	0.113	0.106	0.373	0.192	1.748
31.417	1.531	20.126	32.44	0.576	0.175	0.193	0.478	0.348	1.756
43.481	1.435	17.696	42.26	0.468	0.207	0.194	0.380	0.217	1.788
34.268	1.562	16.886	35.17	0.625	0.161	0.131	0.538	0.364	1.856
45.065	1.766	22.135	55.73	0.588	0.382	0.223	0.592	0.549	2.014
50.948	1.546	24.569	59.54	0.648	0.215	0.150	0.482	0.365	1.076
41.723	1.893	21.103	38.66	0.840	0.261	0.219	0.390	0.239	1.176
46.765	1.490	22.141	46.20	0.697	0.237	0.176	0.476	0.363	1.069
41.056	1.880	20.023	39.81	0.544	0.242	0.184	0.476	0.301	2.616
48.888	1.852	16.908	48.55	0.762	0.197	0.113	0.490	0.392	2.482
47.159	2.045	23.964	52.31	0.664	0.231	0.157	0.531	0.474	1.940
41.132	1.872	16.389	33.10	0.653	0.209	0.105	0.463	0.367	2.112
43.429	2.341	20.008	49.75	0.631	0.290	0.178	0.638	0.434	1.280
38.767	1.047	22.171	45.19	0.524	0.185	0.202	0.482	0.278	2.157
43.574	1.843	20.109	39.26	0.593	0.146	0.137	0.463	0.184	1.720
37.603	0.876	14.956	33.28	0.803	0.160	0.150	0.529	0.357	1.768
39.553	1.894	19.718	37.94	0.633	0.180	0.167	0.492	0.353	1.527
46.761	2.366	36.618	62.60	0.568	0.277	0.201	0.443	0.316	2.139
41.983	1.929	25.483	53.78	0.637	0.180	0.131	0.539	0.410	1.805
42.160	**1.705**	**20.251**	**43.14**	**0.638**	**0.213**	**0.163**	**0.490**	**0.345**	**1.788**
6.889	0.365	5.196	9.87	0.096	0.058	0.036	0.065	0.090	0.415
1.406	0.075	1.061	2.02	0.020	0.012	0.007	0.013	0.018	0.085
39.565	**1.732**	**19.324**	**41.57**	**0.643**	**0.188**	**0.136**	**0.501**	**0.356**	**1.997**
7.704	0.258	4.518	10.61	0.096	0.044	0.027	0.063	0.090	0.399
2.724	0.091	1.597	3.75	0.034	0.015	0.009	0.022	0.032	0.141
43.143	**1.742**	**19.724**	**41.77**	**0.625**	**0.220**	**0.172**	**0.488**	**0.347**	**1.833**
8.283	0.525	7.949	11.11	0.105	0.048	0.034	0.080	0.068	0.292
2.929	0.186	2.810	3.93	0.037	0.017	0.012	0.028	0.024	0.103
43.771	**1.640**	**21.707**	**46.07**	**0.646**	**0.229**	**0.182**	**0.483**	**0.333**	**1.534**
4.266	0.308	1.615	8.59	0.101	0.077	0.034	0.059	0.118	0.448
1.508	0.109	0.571	3.04	0.036	0.027	0.012	0.021	0.042	0.159

Green FF Mz range (N.m)	Green FF Mz max time (s)	Green FF Tz max value (N.m)	Green FF Tz Range (N.m)	Green FF COFxy max	Green BF Fx Range (BW)	Green BF Fy Range (BW)	Green BF Fz max value (BW)	Green BF Fz Range (BW)	Green BF Fz max time (s)
34.641	1.727	21.487	39.89	0.531	0.214	0.131	0.483	0.291	1.582
40.820	1.834	10.938	34.06	0.585	0.192	0.185	0.522	0.385	2.291
25.540	1.349	12.402	24.73	0.529	0.131	0.110	0.428	0.251	1.804
27.759	1.821	19.582	30.66	0.591	0.178	0.206	0.532	0.332	1.809
47.363	1.816	18.658	45.00	0.588	0.239	0.184	0.387	0.291	1.457
36.455	1.954	17.401	37.03	0.665	0.154	0.124	0.530	0.357	1.944
41.020	1.782	19.333	50.22	0.554	0.298	0.228	0.403	0.306	2.410
52.283	1.381	21.935	51.63	0.643	0.206	0.160	0.580	0.425	0.905
36.214	1.672	23.364	40.09	0.587	0.299	0.191	0.473	0.308	0.997
41.743	1.703	13.466		0.692	0.229	0.148	0.529	0.436	2.353
41.659	1.909	22.402	44.80	0.848	0.249	0.175	0.372	0.240	0.876
43.437	2.043	19.405	36.20	0.638	0.221	0.205	0.428	0.249	2.561
45.999	1.724	18.038	47.15	0.857	0.211	0.110	0.511	0.414	2.173
53.163	1.923	24.998	57.82	0.639	0.221	0.170	0.404	0.353	1.970
41.783	1.691	17.737	34.98	0.565	0.197	0.120	0.450	0.304	1.919
47.925	1.821	41.859	55.10	0.794	0.243	0.170	0.452	0.183	1.263
53.370	1.925	18.857	27.35	0.645	0.182	0.196	0.525	0.281	1.733
25.053	1.673	18.548	31.37	0.468	0.149	0.154	0.573	0.285	0.880
45.464	1.770	12.387		0.647	0.184	0.157	0.559	0.398	0.945
38.252	1.822	14.842	36.37	0.586	0.200	0.147	0.572	0.450	1.871
36.001	1.978	19.795	37.49	0.577	0.193	0.169	0.539	0.371	1.543
40.500	1.795	19.132	43.81	0.638	0.253	0.206	0.481	0.357	2.143
47.950	1.857	25.825	51.97	0.722	0.190	0.132	0.589	0.448	1.674
41.061	**1.781**	**19.669**	**40.84**	**0.634**	**0.210**	**0.164**	**0.492**	**0.335**	**1.700**
7.985	0.165	6.205	9.18	0.097	0.042	0.033	0.066	0.073	0.523
1.630	0.034	1.267	1.87	0.020	0.009	0.007	0.014	0.015	0.107
41.581	**1.793**	**18.993**	**42.11**	**0.654**	**0.191**	**0.142**	**0.492**	**0.345**	**1.832**
8.820	0.213	5.066	11.08	0.105	0.033	0.033	0.067	0.075	0.471
3.118	0.075	1.791	3.92	0.037	0.012	0.012	0.024	0.027	0.167
40.768	**1.788**	**19.527**	**40.00**	**0.630**	**0.216**	**0.171**	**0.491**	**0.342**	**1.888**
6.238	0.057	9.527	8.45	0.078	0.028	0.031	0.060	0.086	0.383
2.205	0.020	3.368	2.99	0.027	0.010	0.011	0.021	0.030	0.135
40.800	**1.760**	**20.605**	**40.42**	**0.617**	**0.225**	**0.182**	**0.495**	**0.317**	**1.335**
9.855	0.207	1.922	9.15	0.118	0.058	0.026	0.082	0.062	0.588
3.484	0.073	0.680	3.23	0.042	0.021	0.009	0.029	0.022	0.208

Red FF Mz range (N.m)	Red FF Mz max time (s)	Red FF Tz max value (N.m)	Red BF Tz Range (N.m)	Red FF COFxy max	Red BF Fx Range (BW)	Red BF Fy Range (BW)	Red BF Fz max value (BW)	Red BF Fz Range (BW)	Red BF Fz max time (s)
46.857	1.622	25.336	41.46	0.637	0.198	0.169	0.582	0.336	1.531
38.139	1.522	16.412	40.19	0.597	0.173	0.183	0.424	0.348	1.818
37.152	1.823	14.589	32.67	0.633	0.128	0.133	0.489	0.283	1.601
30.355	1.675	20.195	33.31	0.659	0.178	0.181	0.395	0.231	1.509
31.817	1.982	17.219	32.80	0.417	0.233	0.232	0.629	0.399	1.246
34.523	1.792	15.438	36.37	0.575	0.134	0.146	0.429	0.247	2.087
41.449	1.833	16.597	47.14	0.656	0.364	0.204	0.582	0.533	2.261
41.280	1.924	25.579	51.96	0.628	0.179	0.159	0.502	0.263	0.828
34.514	1.784	21.514	40.29	.	0.310	0.174	0.422	0.327	1.580
43.409	1.724	23.946		0.631	0.209	0.166	0.502	0.408	2.342
46.105	1.034	23.911	46.33	0.537	0.236	0.167	0.479	0.346	1.875
39.181	1.584	19.379	46.19	0.622	0.256	0.174	0.492	0.320	2.318
39.690	1.843	19.584	42.74	0.479	0.253	0.170	0.628	0.505	1.779
41.000	1.953	24.218	52.48	0.867	0.248	0.156	0.427	0.403	2.281
45.542	2.023	18.164	35.04	0.614	0.201	0.117	0.394	0.245	1.815
44.636	1.782	18.411	46.32	0.744	0.269	0.161	0.532	0.351	2.013
32.676	1.933	23.023	43.49	0.610	0.204	0.204	0.489	0.345	1.195
30.736	1.613	23.811	36.15	0.767	0.169	0.150	0.375	0.091	1.192
40.954	1.284	12.860		0.624	0.209	0.129	0.459	0.310	1.336
38.822	1.731	17.212		0.615	0.284	0.199	0.582	0.396	2.391
45.592	1.733	20.368	39.80	0.639	0.190	0.177	0.523	0.346	1.730
35.251	1.494	19.848	38.67	0.692	0.183	0.165	0.499	0.339	1.490
40.720	1.752	17.732	42.04	0.631	0.284	0.203	0.486	0.336	2.494
41.690	2.187	25.391	48.88	0.688	0.189	0.158	0.399	0.217	1.565
39.254	**1.735**	**20.031**	**41.63**	**0.633**	**0.220**	**0.170**	**0.489**	**0.330**	**1.761**
4.982	0.243	3.707	6.01	0.090	0.056	0.026	0.074	0.092	0.444
1.017	0.050	0.757	1.23	0.018	0.011	0.005	0.015	0.019	0.091
40.131	**1.761**	**19.599**	**42.97**	**0.641**	**0.202**	**0.154**	**0.488**	**0.328**	**1.812**
3.596	0.269	5.010	6.93	0.110	0.051	0.017	0.080	0.091	0.371
1.271	0.095	1.771	2.45	0.039	0.018	0.006	0.028	0.032	0.131
40.026	**1.774**	**19.056**	**38.50**	**0.616**	**0.217**	**0.177**	**0.486**	**0.333**	**1.871**
6.084	0.162	2.398	4.99	0.092	0.041	0.033	0.080	0.064	0.410
2.151	0.057	0.848	1.77	0.033	0.015	0.012	0.028	0.023	0.145
37.604	**1.669**	**21.437**	**43.43**	**0.644**	**0.241**	**0.178**	**0.491**	**0.330**	**1.601**
5.191	0.297	3.279	5.48	0.072	0.071	0.022	0.071	0.124	0.545
1.835	0.105	1.159	1.94	0.026	0.025	0.008	0.025	0.044	0.193

Black FF Mz range (N.m)	Black FF Mz max time (s)	Black BF Tz max value (N.m)	Black BF Tz Range (N.m)	Black FF COFxy max	Black BF Fx Range (BW)	Black BF Fy Range (BW)	Black BF Fz max value (BW)	Black BF Fz Range (BW)	Black BF Fz max time (s)
32.261	1.536	19.353	34.93	0.564	0.168	0.126	0.592	0.308	1.398
39.157	1.974	10.560	30.36	0.644	0.215	0.245	0.429	0.243	1.298
43.187	1.820	14.030	28.54	0.624	0.129	0.124	0.385	0.139	1.670
29.646	1.322	21.054	33.83	0.593	0.186	0.192	0.593	0.449	2.075
43.000	1.782	19.177	43.82	0.597	0.251	0.176	0.479	0.349	1.456
33.837	1.823	15.645	31.06	0.578	0.120	0.133	0.464	0.248	2.590
38.911	1.772	17.097	[illegible]	[illegible]	0.360	0.196	0.532	0.500	2.749
46.449	1.862	22.946	52.59	0.595	0.209	0.156	0.590	0.461	0.996
40.020	1.680	20.205	35.13	0.632	0.252	0.217	0.444	0.306	1.549
45.778	1.876	13.998		0.601	0.223	0.157	0.547	0.459	2.109
38.512	1.345	20.089	40.42	0.682	0.221	0.159	0.424	0.306	1.098
41.995	1.781	17.128	36.15	0.622	0.242	0.207	0.536	0.348	2.406
39.651	1.876	16.854	43.80	0.699	0.208	0.121	0.356	0.293	2.957
37.691	1.762	23.560	51.78	0.557	0.246	0.147	0.572	0.553	2.300
44.993	1.682	20.595	37.65	0.468	0.200	0.154	0.423	0.241	1.965
41.584	1.982	22.702	51.09	0.672	0.302	0.168	0.433	0.232	1.175
33.998	1.904	20.438	40.44	0.596	0.194	0.216	0.524	0.407	1.400
31.984	1.835	16.481	32.56	0.527	0.119	0.162	0.468	0.120	1.223
41.651	0.933	11.657		0.678	0.181	0.146	0.425	0.207	1.178
34.532	2.042	16.729		0.511	0.194	0.192	0.413	0.168	2.407
35.959	1.296	23.583	44.28	0.683	0.211	0.170	0.503	0.339	1.825
38.701	1.922	23.794	44.77	0.679	0.213	0.172	0.454	0.295	1.846
39.626	1.723	18.034	39.07	0.624	0.213	0.168	0.492	0.335	1.874
39.307	1.799	24.977	46.35	0.554	0.217	0.170	0.524	0.371	1.884
38.851	**1.722**	**18.778**	**39.93**	**0.608**	**0.211**	**0.170**	**0.483**	**0.320**	**1.809**
4.472	0.261	3.904	7.25	0.061	0.053	0.031	0.068	0.112	0.555
0.913	0.053	0.797	1.48	0.012	0.011	0.006	0.014	0.023	0.113
38.697	**1.759**	**17.900**	**38.94**	**0.609**	**0.189**	**0.147**	**0.482**	**0.309**	**2.048**
3.911	0.200	4.551	8.54	0.056	0.048	0.029	0.088	0.124	0.616
1.383	0.071	1.609	3.02	0.020	0.017	0.010	0.031	0.044	0.218
39.968	**1.721**	**18.713**	**40.01**	**0.610**	**0.225**	**0.179**	**0.487**	**0.331**	**1.722**
5.267	0.224	4.440	6.99	0.067	0.036	0.029	0.061	0.090	0.362
1.862	0.079	1.570	2.47	0.024	0.013	0.010	0.021	0.032	0.128
37.888	**1.681**	**19.722**	**40.99**	**0.603**	**0.220**	**0.184**	**0.481**	**0.320**	**1.658**
4.491	0.368	2.783	7.14	0.067	0.068	0.025	0.062	0.133	0.633
1.588	0.130	0.984	2.52	0.024	0.024	0.009	0.022	0.047	0.224

Yellow FF Mz range (N.m)	Yellow FF Mz max time (s)	Yellow BF Tz max value (N.m)	Yellow BF Tz Range (N.m)	Yellow FF COFxy max	Yellow BF Fx Range (BW)	Yellow BF Fy Range (BW)	Yellow BF Fz max value (BW)	Yellow BF Fz Range (BW)	Yellow BF Fz max time (s)
37.244	1.663	21.300	42.09	0.569	0.194	0.126	0.532	0.394	1.276
54.291	1.525	19.923	50.16	0.468	0.265	0.170	0.323	0.191	1.434
37.392	1.798	15.698	31.70	0.674	0.153	0.127	0.523	0.302	1.892
37.593	1.438	19.373	31.83	0.622	0.169	0.186	0.566	0.398	2.012
45.304	2.091	18.871	45.28	0.645	0.241	0.169	0.426	0.310	1.406
33.489	1.809	15.797	32.78	0.658	0.144	0.125	0.472	0.294	2.209
41.812	1.724	16.980	47.49	0.765	0.357	0.207	0.657	0.585	2.366
52.759	1.355	23.467	55.35	0.744	0.194	0.167	0.525	0.316	0.942
36.714	1.239	20.301	41.68	0.579	0.346	0.222	0.498	0.456	1.131
40.870	1.541	16.724		0.600	0.223	0.152	0.594	0.480	2.056
40.473	1.946	17.662	37.98	0.712	0.227	0.166	0.483	0.338	1.025
44.396	1.434	20.158	43.02	0.660	0.282	0.171	0.343	0.208	2.088
46.223	1.944	19.269	49.74	0.579	0.140	0.114	0.529	0.452	2.685
40.850	1.251	23.876	54.81	0.681	0.264	0.156	0.389	0.355	1.773
38.855	2.506	17.118	33.86	0.588	0.219	0.108	0.568	0.434	1.739
40.359	1.899	21.458	48.28	0.678	0.272	0.173	0.527	0.299	1.468
43.739	1.795	21.895	40.35	0.469	0.197	0.202	0.594	0.423	2.116
33.356	1.828	20.371	39.67	0.608	0.144	0.172	0.419	0.128	1.018
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31.845	2.356	22.789		0.458	0.281	0.196	0.336	0.133	2.349
41.736	1.309	19.681	42.50	0.671	0.232	0.164	0.569	0.421	1.736
40.306	1.634	19.595	42.52	0.724	0.234	0.166	0.355	0.206	2.060
42.737	1.626	19.895	42.43	0.671	0.233	0.165	0.402	0.253	1.777
44.170	1.433	20.116	43.00	0.699	0.237	0.167	0.652	0.507	1.571
41.153	**1.702**	**19.666**	**42.69**	**0.631**	**0.228**	**0.164**	**0.491**	**0.343**	**1.745**
5.457	0.331	2.258	6.81	0.085	0.059	0.029	0.100	0.121	0.477
1.114	0.067	0.461	1.39	0.017	0.012	0.006	0.020	0.025	0.097
40.538	**1.771**	**19.459**	**42.45**	**0.646**	**0.202**	**0.141**	**0.492**	**0.359**	**1.928**
4.671	0.245	2.927	8.32	0.051	0.059	0.023	0.102	0.102	0.458
1.652	0.087	1.035	2.94	0.018	0.021	0.008	0.036	0.036	0.162
42.718	**1.736**	**19.130**	**42.05**	**0.618**	**0.232**	**0.161**	**0.497**	**0.348**	**1.703**
5.234	0.473	1.554	6.91	0.069	0.032	0.024	0.100	0.100	0.252
1.850	0.167	0.549	2.44	0.025	0.011	0.008	0.035	0.035	0.089
40.126	**1.633**	**20.382**	**43.58**	**0.632**	**0.248**	**0.187**	**0.484**	**0.323**	**1.626**
6.565	0.234	2.305	6.00	0.123	0.075	0.022	0.111	0.162	0.648
2.321	0.083	0.815	2.12	0.043	0.027	0.008	0.039	0.057	0.229

Blue BF Mz max value (N.m)	Blue BF Mz Range (N.m)	Blue BF Mz max time (s)	Blue BF Tz Max Value (N.m)	Blue BF Tz Range (N.m)	Blue BF COFxy max
7.930	23.243	1.814	10.505	13.77	0.631
10.070	17.494	2.308	12.450	18.69	0.655
7.900	13.123	2.044	13.084	21.84	0.634
10.371	24.143	2.247	5.347	10.92	0.675
20.129	26.930	1.967	6.630	14.53	0.406
5.654	16.978	2.595	4.700	13.62	0.554
6.941	26.077	2.577	2.708	7.37	0.758
30.755	38.817	1.256	4.912	10.53	0.644
17.225	25.123	1.243	4.069	11.69	0.437
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23.377	29.825	1.447	4.477	7.99	0.534
22.864	36.328	3.091	7.107	16.22	0.595
14.880	25.127	2.566	12.578	15.59	0.688
23.061	29.227	1.873	10.839	15.34	0.686
9.293	43.764	2.326	5.357	5.36	0.687
10.614	19.637	1.629	5.429	10.92	0.579
13.486	27.480	2.229	9.805	14.66	0.807
17.705	40.919	1.120	5.378	12.40	0.558
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14.014	20.027	2.006	9.857	17.69	0.647
13.134	23.648	2.096	4.250	10.25	0.685
12.923	26.057	2.545	5.482	11.37	0.711
17.096	26.974	2.139	7.397	7.40	0.746
14.734	**26.711**	**2.053**	**7.255**	**12.77**	**0.634**
6.512	7.878	0.509	3.188	4.08	0.099
1.329	1.608	0.104	0.651	0.83	0.020
14.198	**24.428**	**2.303**	**9.458**	**14.82**	**0.648**
7.240	7.706	0.464	3.117	4.28	0.064
2.560	2.725	0.164	1.102	1.51	0.023
12.488	**25.436**	**2.147**	**7.222**	**12.78**	**0.623**
3.763	8.815	0.302	2.824	4.58	0.104
1.330	3.116	0.107	0.999	1.62	0.037
17.517	**30.270**	**1.710**	**5.085**	**10.70**	**0.632**
7.714	6.860	0.579	2.242	2.52	0.131
2.727	2.425	0.205	0.792	0.89	0.046

Total
Weight Transfer Times

Shoe	Low Handicap
Blue	0.70
Green	0.68
Red	0.71
Black	0.70
Yellow	0.71
Mean	**0.70**

Shoe	Medium Handicap
Blue	0.49
Green	0.47
Red	0.48
Black	0.49
Yellow	0.49
Mean	**0.48**

Shoe	High Handicap
Blue	0.45
Green	0.43
Red	0.42
Black	0.40
Yellow	0.47
Mean	**0.43**

Green BF Mz max value (N.m)	Green BF Mz Range (N.m)	Green BF Mz max time (s)	Green BF Tz Max Value (N.m)	Green BF Tz Range (N.m)	Green BF COFxy max
6.757	27.516	1.741	10.169	16.30	0.894
10.924	36.427	2.581	8.295	13.48	0.768
6.231	10.332	2.341	13.403	20.28	0.602
10.797	23.097	2.272	4.578	11.07	0.696
12.378	15.318	1.681	6.973	18.98	0.765
7.021	20.018	2.300	4.865	14.32	0.693
5.757	27.030	2.876	2.433	12.41	0.671
20.935	30.872	1.060	6.124	11.08	0.690
11.478	24.945	1.196	5.677	14.13	0.683
10.324		2.112	9.537		0.532
27.867	41.413	1.383	3.202	9.28	0.657
15.958	30.133	3.032	7.681	22.50	0.710
16.848	26.208	2.366	9.994	16.92	0.672
24.382	29.393	2.035	15.597	21.40	0.581
5.850	30.690	2.119	5.715	13.33	0.367
27.653	52.922	1.969	14.766	24.66	0.903
17.048	46.504	2.155	12.538	23.10	0.870
24.595	21.332	1.166	13.186	25.25	0.623
1.925		1.804	3.893		0.583
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7.526	12.756	2.044	5.960	14.97	0.400
16.290	29.238	1.985	4.215	4.22	0.589
11.365	24.160	2.530	5.696	12.17	0.568
18.427	29.192	1.909	5.902	15.81	0.530
13.841	**28.071**	**2.029**	**7.843**	**15.98**	**0.654**
7.462	10.260	0.510	3.853	5.44	0.135
1.523	2.094	0.104	0.787	1.11	0.028
12.194	**24.685**	**2.191**	**8.938**	**18.22**	**0.658**
7.751	7.191	0.419	4.136	3.14	0.114
2.740	2.542	0.148	1.462	1.11	0.040
12.102	**27.910**	**2.163**	**7.690**	**15.52**	**0.625**
6.641	13.731	0.295	3.271	4.76	0.190
2.348	4.855	0.104	1.157	1.68	0.067
17.710	**31.619**	**1.689**	**6.768**	**14.21**	**0.683**
7.584	9.084	0.673	4.361	7.51	0.090
2.681	3.212	0.238	1.542	2.65	0.032

Red BF Mz max value (N.m)	Red BF Mz Range (N.m)	Red BF Mz max time (s)	Red BF Tz Max Value (N.m)	Red BF Tz Range (N.m)	Red BF COFxy max
30.912	43.585	1.889	8.569	19.92	0.683
5.885	21.937	2.171	9.286	16.82	0.736
14.249	27.815	1.708	8.856	17.51	0.689
13.010	27.880	2.178	4.758	12.47	0.574
13.784	26.418	1.570	5.930	10.98	0.866
5.996	19.096	2.130	8.857	19.50	0.526
9.580	26.303	2.475	8.560	14.42	0.597
25.589	33.965	1.053	2.744	15.56	0.679
14.126	31.472	1.250	13.510	20.70	0.638
3.537		2.204	4.297		0.479
24.607	32.511	1.371	4.371	8.52	0.574
14.788	32.714	3.491	5.212	14.47	0.738
14.264	28.671	2.079	9.465	20.62	0.490
22.708	31.145	2.553	7.735	12.92	0.579
9.265	39.566	2.078	8.332	15.49	0.444
18.526	25.671	2.041	6.384	12.37	0.626
14.731	24.248	1.850	6.107	15.85	0.478
16.035	40.983	1.008	4.390	13.52	0.678
2.404		1.973	6.455		0.635
12.534		2.005	6.664		0.689
10.523	24.073	1.827	9.316	19.80	0.592
14.538	26.496	1.893	5.234	12.71	0.477
11.251	27.013	2.512	4.567	16.05	0.786
15.283	27.244	1.754	9.946	18.09	0.624
14.088	**29.467**	**1.961**	**7.064**	**15.63**	**0.620**
6.837	6.168	0.526	2.475	3.38	0.107
1.396	1.259	0.107	0.505	0.69	0.022
15.075	**30.038**	**2.197**	**8.137**	**17.58**	**0.620**
8.892	7.374	0.586	1.595	2.89	0.085
3.144	2.607	0.207	0.564	1.02	0.030
10.723	**27.508**	**2.073**	**6.609**	**14.85**	**0.638**
4.675	5.674	0.279	2.101	3.08	0.148
1.653	2.006	0.099	0.743	1.09	0.052
16.467	**30.854**	**1.613**	**6.447**	**14.47**	**0.601**
5.667	5.755	0.521	3.343	3.68	0.087
2.003	2.035	0.184	1.182	1.30	0.031

Black BF Mz max value (N.m)	Black BF Mz Range (N.m)	Black BF Mz max time (s)	Black BF Tz Max Value (N.m)	Black BF Tz Range (N.m)	Black BF COFxy max
9.133	21.573	1.673	8.278	10.66	0.692
14.493	47.446	1.592	11.902	19.33	0.630
10.299	20.803	1.736	14.130	16.39	0.467
10.709	24.071	2.816	3.101	7.73	0.590
14.162	20.782	1.745	5.645	6.97	0.598
9.092	20.612	2.658	3.905	12.20	0.617
14.825	29.634	3.044	.		0.744
23.693	31.602	1.213	2.985	5.43	0.796
14.351	26.815	1.210	6.588	17.60	0.555
13.141		1.702	7.322		0.613
13.041	17.866	1.474	3.796	6.36	0.581
24.513	34.444	3.424	7.284	13.75	0.668
10.944	18.976	3.031	14.646	17.30	0.602
13.948	33.191	1.870	11.050	16.52	0.711
11.686	36.251	2.172	7.555	11.39	0.572
12.786	28.621	1.655	3.163	11.29	0.691
13.848	23.083	1.819	7.433	10.43	0.625
14.679	35.216	1.343	6.160	19.13	0.420
10.945		1.944	9.248		0.539
13.724		1.736	7.073		0.591
10.359	24.208	1.993	7.435	12.67	0.482
19.938	33.858	2.009	7.391	12.77	0.472
6.438	19.406	2.030	7.153	12.43	0.633
10.633	23.724	2.044	6.786	14.21	0.672
13.391	**27.247**	**1.997**	**7.392**	**12.73**	**0.607**
4.241	7.539	0.590	3.181	4.14	0.090
0.866	1.539	0.120	0.649	0.85	0.018
12.438	**24.760**	**2.298**	**9.416**	**14.43**	**0.621**
5.106	6.356	0.656	3.692	2.45	0.083
1.805	2.247	0.232	1.305	0.87	0.030
11.722	**28.684**	**1.963**	**6.659**	**11.69**	**0.601**
2.607	9.992	0.401	2.815	4.04	0.060
0.922	3.533	0.142	0.995	1.43	0.021
16.012	**28.296**	**1.731**	**5.918**	**11.95**	**0.598**
3.763	6.187	0.605	1.799	5.66	0.126
1.330	2.188	0.214	0.636	2.00	0.045

Yellow BF Mz max value (N.m)	Yellow BF Mz Range (N.m)	Yellow BF Mz max time (s)	Yellow BF Tz Max Value (N.m)	Yellow BF Tz Range (N.m)	Yellow BF COFxy max
5.901	25.480	2.007	11.616	14.06	0.687
19.468	33.180	1.548	12.432	19.69	0.755
18.732	30.245	1.991	14.121	19.82	0.699
10.983	25.404	2.647	6.122	12.56	0.638
11.024	13.552	1.620	5.386	12.54	0.590
7.451	19.251	2.377	6.788	14.25	0.667
26.658	42.226	2.600	2.919	4.93	0.759
28.875	39.461	1.130	2.470	6.04	0.472
13.141	20.703	1.175	4.320	11.03	0.725
3.181		1.872	1.714		0.610
8.369	15.977	1.181	4.706	10.89	0.548
26.174	46.054	3.383	3.483	11.75	0.578
14.930	21.436	3.037	12.446	19.57	0.572
18.232	33.940	1.801	12.711	19.51	0.636
5.448	30.561	1.908	6.498	9.46	0.609
24.969	37.508	1.679	4.445	13.55	0.537
16.711	31.731	2.318	7.272	11.89	0.562
4.404	29.122	0.836	6.270	16.71	0.602
13.400		1.918	9.551		0.593
14.061	27.923	1.949	7.119	12.39	0.736
24.986	38.547	1.946	6.883	15.61	0.698
14.228	27.782	1.967	6.591	12.56	0.547
13.991	27.652	1.965	6.194	11.61	0.690
15.014	**29.416**	**1.950**	**7.046**	**13.35**	**0.631**
7.589	8.508	0.601	3.515	4.11	0.078
1.549	1.737	0.123	0.718	0.84	0.016
15.059	**29.151**	**2.366**	**9.623**	**15.80**	**0.647**
6.952	8.973	0.610	4.066	3.73	0.053
2.458	3.172	0.216	1.438	1.32	0.019
12.920	**27.987**	**1.899**	**6.288**	**13.25**	**0.628**
7.062	7.521	0.342	3.017	3.11	0.080
2.497	2.659	0.121	1.067	1.10	0.028
17.068	**31.109**	**1.638**	**5.549**	**11.02**	**0.620**
8.937	9.919	0.642	2.388	4.40	0.099
3.160	3.507	0.227	0.844	1.56	0.035

3-IRON

(Relevant to Chapter 5)

Blue Handicap	3 IRON Ball impact Time (s)	Blue Weight Traf Time (s)	Blue FF Fx Range (BW)	Blue FF Fy Range (BW)	Blue FF Fz max value (BW)	Blue FF Fz Range (BW)	Blue FF Fz max time (s)	Blue FF Mz max value (N.m)	Blue FF Mz range (N.m)
1	1.470	0.622	0.233	0.273	1.036	0.787	2.034	17.081	31.590
2	1.360	0.338	0.280	0.382	1.114	0.963	1.978	17.125	44.973
1	1.130	0.636	0.220	0.285	1.209	0.937	1.930	18.914	34.882
2	1.830	0.127	0.163	0.364	0.858	0.779	1.854	17.608	32.551
2	1.090	0.415	0.205	0.398	1.461	1.189	1.827	16.105	49.109
1	1.820	0.610	0.213	0.281	0.921	0.757	3.372	12.499	33.357
3	1.330	0.397	0.200	0.332	1.112	0.915	2.196	15.429	36.622
3	0.740	0.508	0.263	0.301	1.088	1.051	1.616	18.996	51.212
3	0.990	0.085	0.300	0.406	0.992	0.972	1.365	14.916	30.380
2	1.790	0.198	0.219	0.364	1.340	1.056	2.648	11.341	32.991
3	6.990	0.591	0.213	0.371	1.457	1.347	1.540	15.490	45.642
1	2.600	0.693	0.241	0.330	1.305	1.081	3.322	20.467	39.273
1	2.610	0.556	0.230	0.315	1.280	1.139	3.254	18.891	50.149
1	1.580	0.902	0.273	0.311	1.076	0.852	2.311	21.511	51.462
2	1.340	0.485	0.148	0.266	0.996	0.639	2.030	17.111	35.938
2	1.180	0.568	0.259	0.331	1.251	1.034	1.854	15.074	43.708
3	1.780	0.355	0.238	0.386	1.010	0.715	2.549	15.418	29.592
3	0.410	0.187	0.226	0.390	0.929	0.788	1.169	18.401	42.980
1	0.000	0.492	0.223	0.335	1.193	0.905	1.862	16.699	47.030
3					.			17.180	
2	1.337	0.416	0.215	0.349	1.337	1.060	2.135	16.970	40.511
3	3.547	0.376	0.196	0.339	1.079	0.961	2.189	21.859	43.843
2	1.673	0.502	0.215	0.353	1.293	1.062	2.448	14.780	39.115
1	1.723	1.558	0.235	0.299	1.096	0.982	3.747	23.495	51.606
TOTAL									
MEAN	**1.753**	**0.505**	**0.226**	**0.337**	**1.149**	**0.955**	**2.227**	**17.223**	**40.805**
SD	1.358	0.124	0.034	0.041	0.169	0.166	0.665	2.828	7.331
SE	0.277	0.025	0.007	0.008	0.034	0.034	0.136	0.118	0.305
	Low Handicap								
Mean	**1.617**	**0.759**	**0.233**	**0.303**	**1.140**	**0.930**	**2.729**	**18.695**	**42.419**
SD	0.835	0.104	0.018	0.023	0.130	0.134	0.768	3.363	8.563
SE	0.295	0.037	0.006	0.008	0.046	0.048	0.271	0.420	1.070
	Medium Handicap								
Mean	**1.450**	**0.381**	**0.213**	**0.351**	**1.206**	**0.973**	**2.097**	**15.764**	**39.862**
SD	0.279	0.057	0.044	0.040	0.201	0.178	0.302	2.058	5.897
SE	0.099	0.020	0.015	0.014	0.071	0.063	0.107	0.257	0.737
	High Handicap								
Mean	**2.255**	**0.357**	**0.234**	**0.361**	**1.095**	**0.964**	**1.803**	**17.211**	**40.039**
SD	2.326	0.023	0.037	0.038	0.172	0.204	0.509	2.415	8.098
SE	0.822	0.008	0.013	0.013	0.061	0.072	0.180	0.302	1.012

Green Handicap	3 IRON Ball impact Time (s)	Green Weight Traf Time (s)	Green FF Fx Range (BW)	Green FF Fy Range (BW)	Green FF Fz max value (BW)	Green FF Fz Range (BW)	Green FF Fz max time (s)	Green FF Mz max value (N.m)	Green FF Mz range (N.m)
	1.150	1.818	0.232	0.267	1.017	0.781	2.685	21.935	39.071
	1.170	0.051	0.233	0.308	1.246	1.139	1.992	12.851	34.634
	1.700	0.602	0.259	0.282	1.166	0.892	2.310	15.524	41.579
	2.000	0.649	0.161	0.345	0.862	0.796	2.627	18.837	33.047
	1.320	0.435	0.258	0.421	1.390	1.169	2.112	17.911	40.831
	1.620	0.642	0.237	0.273	0.835	0.718	2.757	15.329	33.185
	1.510	0.359	0.259	0.362	1.228	1.096	2.507	16.761	32.909
	3.470	0.520	0.212	0.289	0.921	0.880	1.557	28.857	52.681
	0.860	0.436	0.292	0.356	0.987	0.946	1.298	22.995	38.290
	1.490	0.809	0.230	0.371	1.461	1.204	2.343	17.987	40.985
	0.730	0.023	0.201	0.376	1.269	1.185	1.363	24.384	56.974
	2.560	0.628	0.251	0.327	1.373	1.179	3.195	16.388	45.141
	2.300	0.558	0.195	0.323	1.258	1.116	2.867	18.612	45.030
	8.110	0.837	0.283	0.324	1.127	0.864	3.255	23.408	65.326
	1.500	0.035	0.179	0.299	1.076	0.748	2.037	14.358	32.349
	1.230	0.179	0.261	0.277	1.061	0.881	1.463	22.005	38.309
	1.890	0.706	0.256	0.321	1.117	0.926	2.430	23.131	32.371
	0.570	0.214	0.196	0.377	0.802	0.631	1.503	22.724	55.139
	0.000	0.453	0.245	0.384	1.142	0.897	2.725	12.877	42.793
	0.820	0.189	0.207	0.343	1.354	1.038	3.129	10.094	
	1.503	0.416	0.235	0.358	1.339	1.088	2.255	15.474	39.465
	1.450	0.438	0.189	0.331	0.989	0.900	2.249	19.517	41.068
	1.797	0.474	0.256	0.370	1.330	1.148	2.605	17.020	39.627
	2.463	0.574	0.237	0.295	1.005	0.905	2.393	24.266	46.965
TOTAL									
MEAN	**1.801**	**0.502**	**0.232**	**0.332**	**1.140**	**0.963**	**2.319**	**18.885**	**42.077**
SD	1.526	0.046	0.033	0.041	0.188	0.167	0.571	4.521	8.611
SE	0.311	0.009	0.007	0.008	0.038	0.034	0.117	0.188	0.359
	Low Handicap								
Mean	**2.488**	**0.764**	**0.242**	**0.309**	**1.115**	**0.919**	**2.773**	**18.542**	**44.886**
SD	2.420	0.210	0.025	0.038	0.165	0.156	0.336	4.211	9.322
SE	0.856	0.074	0.009	0.014	0.058	0.055	0.119	0.526	1.165
	Medium Handicap								
Mean	**1.501**	**0.381**	**0.227**	**0.343**	**1.221**	**1.021**	**2.179**	**17.055**	**37.406**
SD	0.281	0.094	0.037	0.047	0.203	0.183	0.375	2.847	3.521
SE	0.099	0.033	0.013	0.017	0.072	0.065	0.133	0.356	0.440
	High Handicap								
Mean	**1.413**	**0.361**	**0.226**	**0.344**	**1.083**	**0.950**	**2.004**	**21.058**	**44.205**
SD	0.949	0.005	0.037	0.030	0.190	0.167	0.668	5.654	10.543
SE	0.336	0.002	0.013	0.011	0.067	0.059	0.236	0.707	1.318

Red Handicap	3 IRON Ball impact Time (s)	Red Weight Traf Time (s)	Red FF Fx Range (BW)	Red FF Fy Range (BW)	Red FF Fz max value (BW)	Red FF Fz Range (BW)	Red FF Fz max time (s)	Red FF Mz max value (N.m)	Red FF Mz range (N.m)
	1.450	0.625	0.242	0.322	1.079	0.879	1.911	14.753	41.991
	1.150	0.433	0.210	0.270	1.131	1.088	2.207	14.931	36.407
	1.240	0.661	0.245	0.301	1.183	0.889	2.078	19.635	49.799
	1.860	0.224	0.177	0.334	0.816	0.729	1.817	14.778	40.105
	0.990	0.202	0.291	0.446	1.165	0.938	1.563	13.234	28.409
	2.260	0.601	0.199	0.298	0.919	0.757	3.500	15.346	32.650
	1.280	0.272	0.271	0.380	1.074	0.933	2.191	13.494	33.837
	6.840	0.509	0.215	0.291	0.976	0.922	1.339	17.084	43.671
	0.960	0.300	0.306	0.405	0.978	0.929	1.828	17.020	32.028
	1.500	0.223	0.214	0.359	1.529	1.313	2.165	15.006	40.653
	0.800	0.562	0.203	0.394	1.355	1.259	1.421	21.995	51.222
	2.750	0.754	0.312	0.351	1.634	1.451	3.430	12.253	38.238
	2.300	0.618	0.203	0.324	1.286	1.137	2.952	17.736	40.638
	9.640	0.739	0.291	0.313	1.100	0.849	3.568	21.802	59.470
	1.530	1.443	0.168	0.307	1.068	0.749	2.116	16.469	39.716
	1.170	0.497	0.292	0.330	1.189	0.999	1.726	21.630	45.974
	1.770	1.134	0.253	0.350	1.038	0.824	2.312	19.136	39.559
	0.490	0.037	0.180	0.348	0.916	0.703	1.057	17.055	36.443
	1.550	0.480	0.258	0.360	1.333	1.130	1.972	17.950	45.786
	1.050	0.412	0.193	0.331	0.931	0.615	2.643	15.971	
	1.243	0.362	0.250	0.368	1.292	1.047	1.935	14.225	37.887
	1.640	0.462	0.193	0.342	1.030	0.915	2.246	16.050	40.002
	1.673	0.409	0.291	0.392	1.291	1.107	2.394	22.927	43.428
	3.800	0.576	0.206	0.305	1.060	0.938	2.597	18.389	40.653
TOTAL									
MEAN	**2.122**	**0.522**	**0.236**	**0.343**	**1.141**	**0.962**	**2.207**	**17.036**	**40.807**
SD	2.048	0.043	0.045	0.041	0.197	0.202	0.654	2.944	6.772
SE	0.418	0.009	0.009	0.008	0.040	0.041	0.134	0.123	0.282
	Low Handicap								
Mean	**3.124**	**0.632**	**0.245**	**0.322**	**1.199**	**1.004**	**2.751**	**17.233**	**43.653**
SD	2.760	0.048	0.042	0.023	0.220	0.224	0.709	3.006	8.139
SE	0.976	0.017	0.015	0.008	0.078	0.079	0.251	0.376	1.017
	Medium Handicap								
Mean	**1.390**	**0.474**	**0.237**	**0.351**	**1.185**	**0.996**	**1.990**	**16.650**	**39.072**
SD	0.298	0.151	0.052	0.054	0.205	0.193	0.278	3.604	5.248
SE	0.105	0.054	0.018	0.019	0.072	0.068	0.098	0.451	0.656
	High Handicap								
Mean	**1.854**	**0.461**	**0.227**	**0.355**	**1.037**	**0.887**	**1.880**	**17.226**	**39.537**
SD	2.058	0.033	0.045	0.037	0.139	0.191	0.558	2.489	6.484
SE	0.728	0.012	0.016	0.013	0.049	0.068	0.197	0.311	0.811

Black Handicap	3 IRON Ball impact Time (s)	Black Weight Traf Time (s)	Black FF Fx Range (BW)	Black FF Fy Range (BW)	Black FF Fz max value (BW)	Black FF Fz Range (BW)	Black FF Fz max time (s)	Black FF Mz max value (N.m)	Black FF Mz range (N.m)
	1.390	0.583	0.238	0.298	1.072	0.841	2.020	19.490	36.424
	1.240	0.066	0.233	0.352	0.952	0.768	1.805	14.758	35.399
	1.460	0.808	0.192	0.246	1.133	0.908	2.506	11.211	23.678
	2.010	0.779	0.175	0.334	0.857	0.824	2.778	19.245	36.017
	1.250	0.433	0.253	0.439	1.271	1.099	2.139	17.528	34.280
	1.490	1.416	0.213	0.282	0.933	0.784	3.224	16.210	35.904
	1.260	0.221	0.248	0.326	1.120	0.981	2.302	11.049	26.621
	5.620	-0.692	0.255	0.303	1.101	1.064	1.530	19.731	49.919
	1.100	-0.643	0.259	0.339	0.908	0.861	1.986	20.989	40.351
	1.500	0.154	0.216	0.396	1.513	1.236	2.071	17.943	41.845
	6.890	1.589	0.198	0.357	1.510	1.411	2.546	19.045	48.237
	2.590	0.591	0.257	0.344	1.377	1.183	3.362	18.059	38.569
	2.610	0.521	0.234	0.301	1.256	1.214	3.155	17.152	42.857
	5.110	0.823	0.289	0.320	1.127	0.883	2.634	21.907	43.155
	1.710	0.133	0.155	0.306	0.987	0.670	2.327	20.170	42.027
	1.140	0.493	0.277	0.336	1.188	0.979	1.753	21.447	49.881
	1.850	0.816	0.246	0.376	1.115	0.947	2.462	18.949	34.125
	0.410	1.151	0.198	0.376	0.919	0.736	2.193	22.178	43.082
	1.670	0.481	0.225	0.364	1.225	0.964	1.901	15.898	43.921
	0.940	0.563	0.205	0.308	0.829	0.538	2.809	15.651	31.724
	2.930	0.508	0.226	0.345	1.212	1.077	2.435	22.494	45.338
	2.963	0.575	0.236	0.359	1.236	1.146	2.206	18.678	41.431
	2.673	0.746	0.244	0.336	1.237	1.021	2.823	17.280	38.618
TOTAL									
MEAN	**2.252**	**0.527**	**0.229**	**0.337**	**1.134**	**0.962**	**2.390**	**18.133**	**39.278**
SD	1.602	0.009	0.032	0.041	0.189	0.203	0.482	**3.066**	**6.690**
SE	0.327	0.002	0.007	0.008	0.039	0.041	0.098	**0.133**	**0.291**
	Low Handicap								
Mean	**2.523**	**0.728**	**0.231**	**0.358**	**1.217**	**1.062**	**2.575**	**17.132**	**37.787**
SD	2.115	0.137	0.024	0.043	0.214	0.243	0.569	3.333	7.038
SE	0.748	0.049	0.009	0.015	0.076	0.086	0.201	0.476	1.005
	Medium Handicap								
Mean	**2.085**	**0.452**	**0.219**	**0.314**	**1.019**	**0.834**	**2.408**	**18.858**	**40.426**
SD	1.374	0.065	0.045	0.034	0.146	0.178	0.324	2.499	5.396
SE	0.486	0.023	0.016	0.012	0.052	0.063	0.115	0.312	0.675
	High Handicap								
Mean	**2.183**	**0.424**	**0.238**	**0.341**	**1.176**	**1.004**	**2.210**	**18.284**	**39.436**
SD	1.494	0.200	0.022	0.038	0.164	0.129	0.526	3.485	8.083
SE	0.528	0.071	0.008	0.013	0.058	0.046	0.186	0.436	1.010

Yellow Handicap	3 IRON Ball impact Time (s)	Yellow Weight Traf Time (s)	Yellow FF Fx Range (BW)	Yellow FF Fy Range (BW)	Yellow FF Fz max value (BW)	Yellow FF Fz Range (BW)	Yellow FF Fz max time (s)	Yellow FF Mz max value (N.m)	Yellow FF Mz range (N.m)
	1.170	0.658	0.220	0.281	1.033	0.798	1.818	19.354	34.357
	1.170	0.359	0.243	0.332	1.171	1.037	1.828	19.592	50.182
	1.730	0.606	0.214	0.294	1.154	0.956	2.408	15.494	38.124
	2.080	0.168	0.166	0.363	0.917	0.760	3.095	17.001	35.107
	1.810	0.431	0.237	0.385	1.384	1.159	2.326	15.519	40.167
	1.790	0.448	0.214	0.300	0.913	0.742	3.417	16.030	34.199
	1.420	0.541	0.251	0.329	1.078	0.934	2.418	14.591	30.214
	0.500	0.339	0.243	0.310	1.074	1.037	1.391	.	
	0.850	0.491	0.305	0.382	0.913	0.868	1.718	21.022	34.897
	1.530	0.219	0.210	0.373	1.359	1.081	2.413	18.784	40.281
	4.540	1.094	0.221	0.378	1.506	1.406	1.797	18.060	42.597
	2.930	1.502	0.266	0.330	1.370	1.165	3.771	12.818	38.943
	2.680	0.465	0.209	0.354	1.274	1.185	3.234	17.693	52.991
	1.560	0.466	0.253	0.320	1.071	0.869	2.086	22.586	44.014
	1.090	0.033	0.152	0.298	1.024	0.652	1.853	23.120	40.454
	1.170	0.537	0.259	0.334	1.189	0.979	1.731	21.032	49.590
	1.700	0.367	0.264	0.373	1.149	0.919	2.333	17.346	36.911
	0.270	0.901	0.163	0.357	0.835	0.592	1.984	14.842	36.746
	2.520				.		.	.	
	0.000	0.652	0.150	0.335	0.892	0.467	3.925	15.207	27.957
	1.760	0.582	0.221	0.344	1.180	1.031	2.667	12.901	37.470
	2.470	0.495	0.243	0.374	1.269	1.154	2.144	17.073	41.663
	1.953	0.609	0.236	0.330	1.178	0.964	2.922	15.080	36.884
TOTAL									
MEAN	**1.682**	**0.544**	**0.224**	**0.340**	**1.133**	**0.943**	**2.422**	**17.388**	**39.226**
SD	0.965	0.015	0.039	0.031	0.180	0.218	0.702	2.934	6.225
SE	0.197	0.003	0.008	0.006	0.037	0.045	0.143	0.147	0.311
	Low Handicap								
Mean	**2.193**	**0.766**	**0.225**	**0.352**	**1.245**	**1.073**	**2.551**	**17.329**	**40.438**
SD	1.369	0.033	0.033	0.023	0.217	0.253	0.770	3.385	7.125
SE	0.484	0.012	0.012	0.008	0.077	0.089	0.272	0.564	1.188
	Medium Handicap								
Mean	**1.369**	**0.446**	**0.213**	**0.331**	**1.034**	**0.815**	**2.381**	**17.879**	**41.267**
SD	0.770	0.001	0.055	0.039	0.131	0.204	0.763	3.383	5.646
SE	0.272	0.001	0.019	0.014	0.046	0.072	0.270	0.423	0.706
	High Handicap								
Mean	**1.549**	**0.433**	**0.237**	**0.337**	**1.134**	**0.960**	**2.339**	**16.877**	**35.855**
SD	0.577	0.008	0.022	0.028	0.137	0.112	0.652	2.273	5.419
SE	0.204	0.003	0.008	0.010	0.048	0.040	0.231	0.284	0.677

Blue FF Mz max time (s)	Blue FF Tz max value (N.m)	Blue FF Tz Range (N.m)	Blue FF COFxy max	Blue BF Fx Range (BW)	Blue BF Fy Range (BW)	Blue BF Fz max value (BW)	Blue BF Fz Range (BW)	Blue BF Fz max time (s)	Blue BF Mz max value (N.m)
1.486	21.144	42.223	0.457	0.176	0.193	0.740	0.529	1.412	10.787
1.788	9.176	31.659	0.732	0.233	0.343	0.824	0.630	1.640	6.472
1.228	13.605	32.579	0.838	0.167	0.260	0.721	0.602	1.294	13.686
2.454	18.170	29.274	0.441	0.169	0.326	0.969	0.779	1.727	8.170
1.476	15.039	43.411	0.846	0.233	0.279	0.685	0.586	1.413	3.934
1.823	16.186	36.021	0.442	0.136	0.260	0.823	0.680	2.762	7.618
1.745	15.750	35.321	0.718	0.176	0.281	0.799	0.662	1.799	8.352
1.251	11.126	44.940	0.625	0.218	0.240	1.000	0.859	1.108	6.470
0.962	18.591	36.122	0.837	0.246	0.252	1.130	1.019	1.280	9.865
2.084	18.630	41.312	0.455	0.229	0.287	0.627	0.552	2.450	10.120
1.217	21.859	44.260	0.633	0.232	0.445	0.918	0.835	0.949	0.730
2.660	14.808	33.362	0.599	0.225	0.233	0.779	0.637	2.629	2.541
2.886	18.759	49.701	0.858	0.173	0.257	0.799	0.739	2.698	5.578
1.382	21.655	54.997	0.587	0.187	0.299	0.782	0.729	1.409	11.948
0.441	13.378	31.749	0.457	0.141	0.284	0.720	0.586	1.546	10.353
1.458	19.337	50.703	0.616	0.252	0.250	0.765	0.537	1.287	12.674
2.128	19.759	41.689	0.555	0.175	0.315	0.630	0.322	2.194	9.373
1.065	25.457	45.036	0.678	0.164	0.319	0.890	0.681	0.983	4.931
0.936	12.356	43.198	0.684	0.187	0.301	0.733	0.588	1.370	2.750
.	.					.		.	.
1.596	12.425	35.767	0.814	0.210	0.275	0.678	0.580	1.719	5.913
1.831	18.738	36.518	0.506	0.179	0.343	0.903	0.765	1.813	5.506
1.960	15.199	37.365	0.822	0.211	0.264	0.754	0.628	1.947	4.942
1.987	25.357	53.554	0.641	0.176	0.252	0.874	0.759	2.189	6.556
1.645	**17.239**	**40.468**	**0.645**	**0.195**	**0.285**	**0.806**	**0.664**	**1.722**	**7.359**
0.580	4.292	7.240	0.145	0.033	0.050	0.122	0.140	0.541	3.388
0.118	0.876	1.478	0.029	0.007	0.010	0.025	0.029	0.110	0.692
1.798	**17.984**	**43.204**	**0.638**	**0.178**	**0.257**	**0.782**	**0.658**	**1.970**	**7.683**
0.687	4.513	8.870	0.154	0.025	0.035	0.051	0.082	0.664	4.146
0.243	1.596	3.136	0.054	0.009	0.012	0.018	0.029	0.235	1.466
1.657	**15.169**	**37.655**	**0.648**	**0.210**	**0.288**	**0.753**	**0.610**	**1.716**	**7.822**
0.596	3.485	7.186	0.178	0.037	0.031	0.106	0.076	0.359	3.029
0.211	1.232	2.541	0.063	0.013	0.011	0.038	0.027	0.127	1.071
1.457	**18.754**	**40.555**	**0.650**	**0.199**	**0.314**	**0.896**	**0.735**	**1.446**	**6.461**
0.442	4.525	4.428	0.109	0.033	0.069	0.156	0.218	0.487	3.155
0.156	1.600	1.566	0.039	0.012	0.024	0.055	0.077	0.172	1.116

Green FF Mz max time (s)	Green FF Tz max value (N.m)	Green FF Tz Range (N.m)	Green FF COFxy max	Green BF Fx Range (BW)	Green BF Fy Range (BW)	Green BF Fz max value (BW)	Green BF Fz Range (BW)	Green BF Fz max time (s)	Green BF Mz max value (N.m)
1.224	21.935	43.535	0.798	0.208	0.190	0.767	0.617	0.866	10.406
1.846	10.851	36.819	0.672	0.202	0.291	0.824	0.675	1.941	4.896
2.149	15.524	35.664	0.663	0.159	0.257	0.702	0.493	1.707	12.628
2.680	18.837	32.318	0.486	0.185	0.288	0.973	0.846	1.977	8.842
1.543	17.911	43.962	0.744	0.249	0.248	0.747	0.627	1.677	9.180
1.755	15.329	32.698	0.581	0.135	0.229	0.753	0.690	2.114	7.312
2.276	16.761	45.600	0.649	0.274	0.234	0.942	0.842	2.148	14.787
1.074	18.857	47.779	0.541	0.191	0.223	0.994	0.852	1.037	10.929
0.496	22.995	43.411	0.682	0.284	0.227	0.988	0.876	0.862	13.684
0.940	12.987	38.191	0.559	0.236	0.254	0.634	0.533	1.533	0.745
1.097	24.384	52.705	0.546	0.254	0.437	0.964	0.862	1.340	1.995
3.006	16.388	35.113	0.574	0.229	0.219	0.800	0.655	2.567	6.661
2.810	18.612	48.799	0.993	0.205	0.263	0.828	0.758	2.308	6.426
2.925	23.408	59.001	0.668	0.184	0.296	0.753	0.698	2.418	14.705
1.180	13.358	32.675	0.740	0.175	0.376	0.799	0.709	2.002	7.653
1.419	22.005	47.775	0.789	0.235	0.219	0.799	0.508	1.284	10.059
1.868	17.131	26.721	0.675	0.163	0.238	0.770	0.558	1.724	6.307
1.341	27.724	43.336	0.575	0.104	0.351	0.842	0.473	1.289	-0.483
0.713	12.877	42.971	0.559	0.191	0.312	0.762	0.597	2.272	3.116
1.236	7.094	28.196	0.735	0.206	0.287	0.631	0.506	2.941	1.464
1.544	14.474	38.273	0.655	0.215	0.253	0.694	0.551	1.839	7.518
1.844	19.517	39.240	0.856	0.191	0.318	0.897	0.800	1.811	6.050
2.275	17.020	41.558	0.783	0.250	0.234	0.830	0.708	2.131	10.209
1.880	24.266	49.758	0.572	0.177	0.238	0.858	0.767	1.820	8.222
1.713	**17.927**	**41.087**	**0.671**	**0.204**	**0.270**	**0.815**	**0.675**	**1.817**	**7.638**
0.694	4.840	7.864	0.119	0.043	0.057	0.104	0.130	0.525	4.252
0.142	0.988	1.605	0.024	0.009	0.012	0.021	0.027	0.107	0.868
2.058	**18.542**	**43.442**	**0.676**	**0.186**	**0.250**	**0.778**	**0.659**	**2.009**	**8.685**
0.833	4.211	8.914	0.151	0.030	0.040	0.049	0.090	0.545	3.724
0.294	1.489	3.152	0.053	0.010	0.014	0.017	0.032	0.193	1.317
1.678	**15.930**	**38.947**	**0.679**	**0.218**	**0.270**	**0.787**	**0.645**	**1.798**	**7.388**
0.571	3.658	5.328	0.109	0.029	0.049	0.101	0.113	0.282	3.181
0.202	1.293	1.884	0.039	0.010	0.017	0.036	0.040	0.100	1.125
1.404	**19.308**	**40.874**	**0.657**	**0.208**	**0.289**	**0.878**	**0.721**	**1.644**	**6.842**
0.564	6.220	9.151	0.106	0.061	0.076	0.126	0.176	0.673	5.777
0.200	2.199	3.235	0.038	0.021	0.027	0.045	0.062	0.238	2.043

Red FF Mz max time (s)	Red FF Tz max value (N.m)	Red FF Tz Range (N.m)	Red FF COFxy max	Red BF Fx Range (BW)	Red BF Fy Range (BW)	Red BF Fz max value (BW)	Red BF Fz Range (BW)	Red BF Fz max time (s)	Red BF Mz max value (N.m)
1.555	14.753	30.733	0.491	0.203	0.212	0.785	0.548	1.286	15.596
2.159	4.931	22.288	0.856	0.138	0.243	0.646	0.607	1.774	10.230
1.591	9.635	32.165	0.814	0.177	0.268	0.679	0.520	1.417	11.680
2.096	14.778	20.619	0.396	0.154	0.307	0.971	0.779	1.593	11.232
1.343	13.034	25.315	0.488	0.162	0.283	0.727	0.421	1.361	12.209
2.269	15.346	35.113	0.433	0.149	0.253	0.831	0.712	2.900	10.353
2.086	13.494	44.202	0.876	0.330	0.238	0.845	0.763	1.919	12.953
1.010	37.084	65.452	0.623	0.198	0.236	0.979	0.853	0.830	3.581
0.491	12.070	29.056	0.807	0.300	0.274	0.897	0.784	1.528	17.339
1.099	11.006	38.643	0.687	0.208	0.245	0.635	0.549	1.942	-0.443
0.600	13.995	38.286	0.602	0.237	0.442	0.924	0.810	0.860	3.234
2.958	12.253	38.568	0.949	0.313	0.205	0.762	0.652	2.676	3.476
2.862	17.736	46.742	0.568	0.209	0.251	0.821	0.750	2.334	8.029
2.909	21.802	55.323	0.513	0.183	0.305	0.760	0.704	2.829	13.363
1.340	16.469	34.783	0.497	0.164	0.358	0.803	0.660	0.674	0.114
1.623	22.630	56.096	0.593	0.290	0.229	0.791	0.568	1.229	15.378
1.874	20.136	42.806	0.653	0.208	0.270	0.775	0.647	1.177	5.989
1.160	20.095	41.249	0.655	0.145	0.330	0.787	0.546	1.020	2.254
1.334	12.950	40.577	0.599	0.178	0.319	0.805	0.670	1.492	0.510
1.648	15.571	34.686	0.768	0.313	0.262	0.937	0.812	2.231	7.871
1.344	11.225	32.041	0.663	0.182	0.265	0.680	0.497	1.573	7.815
1.655	18.040	34.673	0.477	0.180	0.334	0.909	0.767	1.784	8.273
2.129	12.927	36.028	0.771	0.268	0.242	0.778	0.612	1.985	9.546
2.047	23.389	49.102	0.697	0.186	0.247	0.877	0.771	2.021	7.321
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.716	**16.056**	**38.523**	**0.645**	**0.211**	**0.276**	**0.808**	**0.667**	**1.685**	**8.246**
0.657	6.254	10.654	0.150	0.059	0.053	0.097	0.117	0.611	5.089
0.134	1.277	2.175	0.031	0.012	0.011	0.020	0.024	0.125	1.039
2.191	**15.983**	**41.040**	**0.633**	**0.200**	**0.257**	**0.790**	**0.666**	**2.119**	**8.791**
0.663	4.738	8.685	0.176	0.049	0.040	0.059	0.090	0.661	5.037
0.235	1.675	3.071	0.062	0.017	0.014	0.021	0.032	0.234	1.781
1.641	**13.375**	**33.227**	**0.619**	**0.196**	**0.272**	**0.754**	**0.586**	**1.516**	**8.260**
0.427	5.057	11.372	0.155	0.056	0.043	0.109	0.107	0.430	5.643
0.151	1.788	4.021	0.055	0.020	0.015	0.039	0.038	0.152	1.995
1.315	**18.811**	**41.301**	**0.683**	**0.239**	**0.298**	**0.882**	**0.748**	**1.419**	**7.687**
0.591	7.976	10.959	0.128	0.068	0.069	0.073	0.101	0.525	5.215
0.209	2.820	3.875	0.045	0.024	0.024	0.026	0.036	0.186	1.844

Black FF Mz max time (s)	Black FF Tz max value (N.m)	Black FF Tz Range (N.m)	Black BF COFxy max	Black BF Fx Range (BW)	Black BF Fy Range (BW)	Black BF Fz max value (BW)	Black BF Fz Range (BW)	Black BF Fz max time (s)	Black BF Mz max value (N.m)
1.269	19.490	37.605	0.487	0.186	0.210	0.752	0.552	1.437	9.372
0.929	12.758	37.406	0.457	0.179	0.345	0.808	0.597	1.739	2.841
2.001	11.211	27.233	0.578	0.134	0.226	0.629	0.479	1.698	12.368
2.590	19.245	34.356	0.441	0.162	0.272	0.969	0.791	1.999	10.649
1.646	17.528	38.790	0.734	0.258	0.257	0.797	0.650	1.706	13.185
1.288	16.210	34.039	0.444	0.146	0.250	0.828	0.757	1.809	7.517
1.831	11.049		0.701	0.296	0.230	0.875	0.788	2.081	13.705
1.150	19.731		0.702	0.215	0.253	1.000	0.865	2.223	9.433
1.368	20.989	38.657	0.734	0.247	0.264	1.102	0.997	2.629	6.353
0.830	12.943	36.196	0.642	0.216	0.245	0.607	0.535	1.917	1.363
1.098	19.045	42.304	0.614	0.220	0.403	0.794	0.696	0.957	1.294
2.583	18.059	37.772	0.688	0.231	0.224	0.788	0.636	2.771	2.904
3.083	17.152	45.708	0.796	0.173	0.243	0.817	0.770	2.634	13.481
1.457	21.907	49.762	0.528	0.202	0.307	0.788	0.721	1.811	6.751
1.484	20.870	37.591	0.730	0.162	0.372	0.769	0.650	2.194	1.824
1.637	21.457	50.885	0.587	0.285	0.248	0.757	0.518	1.260	7.493
2.127	18.949	31.793	0.727	0.200	0.262	0.807	0.667	1.646	7.204
1.134	22.278	40.931	0.632	0.138	0.342	0.688	0.389	1.042	10.091
0.757	11.898		0.619	0.198	0.306	0.750	0.625	1.420	10.162
1.606	15.651	36.003	0.521	0.288	0.265	1.015	0.855	2.246	4.618
1.788	22.494	34.023	0.568	0.206	0.248	0.841	0.707	1.927	6.087
1.799	18.678	41.365	0.743	0.225	0.292	0.911	0.811	1.632	8.578
1.539	17.280	39.442	0.526	0.199	0.256	0.753	0.662	2.077	7.134
1.608	**17.690**	**38.593**	**0.617**	**0.207**	**0.275**	**0.819**	**0.683**	**1.863**	**7.583**
0.581	3.598	5.645	0.107	0.046	0.050	0.118	0.139	0.473	3.849
0.119	0.734	1.152	0.022	0.009	0.010	0.024	0.028	0.097	0.786
1.716	**17.728**	**40.336**	**0.635**	**0.200**	**0.296**	**0.778**	**0.628**	**1.847**	**7.276**
0.816	2.823	2.928	0.117	0.040	0.067	0.044	0.119	0.707	5.098
0.289	0.998	1.035	0.041	0.014	0.024	0.016	0.042	0.250	1.802
1.697	**18.505**	**37.821**	**0.595**	**0.201**	**0.276**	**0.867**	**0.732**	**1.956**	**7.564**
0.431	3.510	6.363	0.122	0.051	0.050	0.158	0.168	0.389	3.394
0.153	1.241	2.249	0.043	0.018	0.018	0.056	0.060	0.137	1.200
1.426	**16.841**	**37.387**	**0.624**	**0.220**	**0.255**	**0.808**	**0.683**	**1.785**	**7.870**
0.497	4.466	7.705	0.093	0.049	0.022	0.113	0.121	0.326	3.545
0.176	1.579	2.724	0.033	0.017	0.008	0.040	0.043	0.115	1.253

Yellow FF Mz max time (s)	Yellow FF Tz max value (N.m)	Yellow FF Tz Range (N.m)	Yellow FF COFxy max	Yellow BF Fx Range (BW)	Yellow BF Fy Range (BW)	Yellow BF Fz max value (BW)	Yellow BF Fz Range (BW)	Yellow BF Fz max time (s)	Yellow BF Mz max value (N.m)
1.467	19.354	41.001	0.497	0.215	0.191	0.742	0.570	1.160	13.917
1.598	9.592	35.827	0.550	0.249	0.307	0.789	0.683	1.469	7.061
2.274	15.494	34.760	0.929	0.180	0.275	0.691	0.501	1.803	5.634
2.699	17.001	36.898	0.416	0.156	0.353	0.974	0.848	2.927	9.740
1.310	15.519	42.163	0.746	0.249	0.257	0.735	0.626	1.896	7.458
1.322	16.030	35.118	0.865	0.153	0.258	0.824	0.733	2.969	9.388
2.040	.		.	0.294	0.249	0.852	0.789	1.878	2.124
0.795	.		0.778	0.208	0.253	1.001	0.904	1.053	5.462
1.211	21.022	40.501	.	0.330	0.244	1.144	1.090	1.227	7.440
1.214	8.884	31.626	0.447	0.239	0.253	0.627	0.534	2.194	-0.724
0.965	18.060	38.534	0.567	0.192	0.457	0.916	0.821	0.703	2.445
3.606	12.818	31.735	0.679	0.284	0.204	0.773	0.671	2.269	6.439
2.794	17.693	30.055	0.747	0.125	0.282	0.829	0.778	2.769	15.338
0.770	22.586	41.183	0.475	0.196	0.305	0.837	0.749	1.619	10.027
0.602	13.020	37.948	0.470	0.185	0.282	0.768	0.664	1.820	2.336
1.608	21.332	52.787	0.600	0.274	0.239	0.758	0.537	1.193	10.229
1.744	22.346	39.015	0.541	0.201	0.300	0.701	0.492	1.967	12.076
1.050	19.842	41.110	0.690	0.130	0.348	0.785	0.466	1.083	2.154
.	.		.			.		.	.
3.227	15.207	34.231	0.656	0.241	0.331	0.942	0.787	3.273	5.246
2.079	12.901	35.177	0.580	0.222	0.266	0.844	0.739	2.086	5.229
1.570	18.073	36.563	0.961	0.245	0.310	0.906	0.829	1.649	5.920
1.728	15.080	34.915	0.517	0.218	0.255	0.765	0.672	2.313	8.782
1.712	**16.593**	**37.557**	**0.635**	**0.218**	**0.283**	**0.827**	**0.704**	**1.878**	**6.987**
0.801	3.913	4.973	0.161	0.053	0.057	0.117	0.153	0.687	4.029
0.163	0.799	1.015	0.033	0.011	0.012	0.024	0.031	0.140	0.822
1.865	**15.515**	**36.334**	**0.642**	**0.207**	**0.301**	**0.799**	**0.674**	**1.786**	**7.097**
0.980	3.476	4.555	0.096	0.061	0.082	0.059	0.114	0.737	4.423
0.347	1.229	1.610	0.034	0.022	0.029	0.021	0.040	0.261	1.564
1.728	**17.720**	**37.886**	**0.629**	**0.219**	**0.286**	**0.875**	**0.755**	**1.934**	**7.532**
0.929	3.190	2.759	0.228	0.054	0.051	0.147	0.183	0.764	3.592
0.328	1.128	0.975	0.081	0.019	0.018	0.052	0.065	0.270	1.270
1.543	**16.299**	**38.744**	**0.635**	**0.227**	**0.260**	**0.801**	**0.675**	**1.906**	**6.255**
0.465	5.668	8.274	0.156	0.047	0.019	0.120	0.156	0.644	4.600
0.164	2.004	2.925	0.055	0.017	0.007	0.043	0.055	0.228	1.626

Blue BF Mz Range (N.m)	Blue BF Mz max time (s)	Blue BF Tz Max Value (N.m)	Blue BF Tz Range (N.m)	Blue BF COFxy max
24.406	1.511	6.943	10.142	0.435
13.392	1.716	12.502	16.844	0.689
26.115	1.410	10.365	12.565	0.426
15.959	2.173	4.481	11.208	0.564
12.850	1.573	4.444	6.603	0.786
12.596	2.846	6.647	14.788	0.674
16.880	2.000	6.484	11.291	0.525
18.720	1.217	3.546	5.389	0.845
18.717	0.895	6.809	16.447	0.997
23.013	1.806	5.333	10.986	0.511
8.559	1.408	5.669	8.365	0.563
14.149	3.116	5.688	14.758	0.404
12.462	2.777	12.459	14.578	0.896
24.405	1.634	9.532	15.066	0.604
23.382	1.362	6.382	7.734	0.503
23.384	1.627	7.536	14.694	0.673
22.200	2.240	8.046	15.868	0.416
19.050	0.936	5.995	14.471	0.644
10.245	1.595	7.154	9.862	0.569
17.326	1.596	5.714	9.052	0.458
12.371	2.142	5.599	11.454	0.634
14.626	2.230	5.539	10.884	0.455
14.593	2.280	7.551	11.585	0.805
17.365	**1.830**	**6.975**	**11.941**	**0.612**
5.107	0.578	2.318	3.220	0.165
1.042	0.118	0.473	0.657	0.034
17.371	**2.146**	**8.292**	**12.918**	**0.601**
6.450	0.692	2.279	2.178	0.182
2.280	0.245	0.806	0.770	0.064
17.991	**1.760**	**6.491**	**11.001**	**0.580**
4.580	0.301	2.627	3.415	0.122
1.619	0.106	0.929	1.208	0.043
16.643	**1.548**	**6.021**	**11.898**	**0.661**
4.636	0.573	1.376	4.052	0.198
1.639	0.202	0.487	1.432	0.070

Total
Weight Transfer Times

Shoe	Low Handicap
Blue	0.76
Green	0.76
Red	0.63
Black	0.73
Yellow	0.77
Mean	**0.73**

Shoe	Medium Handicap
Blue	0.38
Green	0.38
Red	0.47
Black	0.45
Yellow	0.45
Mean	**0.43**

Shoe	High Handicap
Blue	0.36
Green	0.36
Red	0.46
Black	0.42
Yellow	0.43
Mean	**0.41**

Green BF Mz Range (N.m)	Green BF Mz max time (s)	Green BF Tz Max Value (N.m)	Green BF Tz Range (N.m)	Green FF COFxy max
23.451	1.332	7.341	9.318	0.457
18.504	1.862	8.840	16.426	1.447
21.576	1.800	11.291	13.691	0.424
15.415	2.441	4.238	10.206	0.574
13.075	1.947	5.718	7.575	0.461
14.884	2.432	5.867	13.264	0.618
29.333	2.450	2.834	5.173	0.859
18.478	1.258	3.257	6.784	0.649
22.023	1.233	10.291	18.427	1.229
12.984	1.477	7.186	10.820	0.631
14.716	1.194	3.834	8.272	0.324
21.090	2.948	5.265	7.570	0.422
13.990	2.340	10.755	11.766	0.784
20.038	2.535	12.951	22.054	0.589
20.112	2.207	7.490	11.140	0.569
17.945	1.604	5.955	8.054	0.624
13.497	2.105	6.758	9.008	0.545
3.533	1.337	10.107	27.042	0.603
11.944	1.667	6.324	9.350	0.567
	0.270	4.763		0.462
15.878	1.741	6.732	13.362	0.505
15.005	2.022	4.646	14.247	0.172
21.166	2.448	4.606	10.106	0.581
15.784	2.010	6.626	14.271	0.684
17.149	**1.861**	**6.820**	**12.084**	**0.616**
5.119	0.590	2.674	5.131	0.265
1.045	0.121	0.546	1.047	0.054
17.845	**2.133**	**8.303**	**12.661**	**0.568**
4.198	0.527	2.912	4.490	0.130
1.484	0.186	1.030	1.587	0.046
16.885	**1.966**	**6.345**	**10.961**	**0.674**
3.057	0.368	1.531	2.851	0.317
1.081	0.130	0.541	1.008	0.112
16.655	**1.484**	**5.811**	**12.708**	**0.605**
7.974	0.687	2.956	7.808	0.326
2.819	0.243	1.045	2.761	0.115

Red BF Mz Range (N.m)	Red BF Mz max time (s)	Red BF Tz Max Value (N.m)	Red BF Tz Range (N.m)	Red FF COFxy max
22.944	1.796	12.477	22.022	0.562
25.171	1.853	14.119	22.373	1.158
22.496	1.792	11.569	20.941	0.505
26.861	2.101	17.387	27.242	0.619
22.076	1.760	6.251	12.252	0.425
19.643	2.827	6.176	13.518	0.678
24.376	1.864	2.046	4.610	0.747
12.752	0.969	3.138	6.004	0.654
30.494	1.297	10.515	19.468	0.426
12.600	1.777	2.692	4.937	0.721
13.671	1.280	4.768	8.040	0.680
21.513	3.233	3.756	5.367	0.629
16.940	2.406	12.003	20.653	0.768
17.304	2.918	12.232	16.674	0.612
13.814	1.589	4.054	6.019	0.617
22.257	1.305	1.314	6.873	0.687
12.289	1.940	5.328	9.259	0.602
18.683	1.246	4.077	12.685	0.571
8.172	1.932	5.769	8.854	0.565
	1.729	7.322		0.535
19.057	1.776	6.838	12.710	0.550
20.058	2.069	9.444	17.600	0.659
19.522	2.286	4.018	12.743	0.600
16.445	2.067	7.106	11.058	0.700
19.093	**1.909**	**7.267**	**13.126**	**0.636**
5.343	0.543	4.254	6.604	0.142
1.091	0.111	0.868	1.348	0.029
18.182	**2.371**	**8.886**	**14.886**	**0.627**
4.782	0.561	3.537	6.182	0.085
1.691	0.198	1.250	2.186	0.030
20.170	**1.806**	**7.084**	**13.143**	**0.672**
5.030	0.298	5.702	7.951	0.216
1.778	0.105	2.016	2.811	0.076
18.903	**1.549**	**5.830**	**11.095**	**0.609**
6.766	0.400	3.006	5.710	0.099
2.392	0.141	1.063	2.019	0.035

Black BF Mz Range (N.m)	Black BF Mz max time (s)	Black BF Tz Max Value (N.m)	Black BF Tz Range (N.m)	Black BF COFxy max
17.899	1.445	6.872	10.666	0.426
8.604	1.930	8.405	13.546	0.638
21.944	1.848	9.382	11.147	0.300
16.904	2.352	2.132	7.324	0.343
19.611	1.991	4.431	6.703	0.482
17.300	2.131	5.431	13.158	0.730
30.288	2.294	1.934	11.385	0.698
17.951	1.217	5.606	7.798	0.821
13.902	1.275	4.591	13.943	0.919
10.683	1.619	7.197	11.237	0.633
7.847	1.389	3.835	6.915	0.520
12.595	3.149	6.970	16.222	0.434
20.413	2.638	7.007	9.480	1.065
13.128	1.883	8.089	15.461	0.869
12.130	1.987	5.236	12.030	0.535
14.376	1.348	1.563	7.359	0.704
16.280	1.737	6.245	9.530	0.627
24.483	1.062	4.980	19.775	0.664
21.054	1.680	9.357	13.333	0.552
[illegible]	1.759	6.932	16.667	0.612
14.533	2.084	4.726	9.895	0.058
15.443	1.823	5.966	10.260	0.497
14.560	2.195	7.171	14.269	0.591
16.451	**1.862**	**5.829**	**11.657**	**0.596**
5.214	0.483	2.160	3.452	0.216
1.064	0.099	0.441	0.705	0.044
15.445	**2.051**	**6.114**	**12.416**	**0.628**
6.287	0.708	1.693	4.914	0.210
2.223	0.250	0.599	1.737	0.074
13.925	**1.797**	**6.150**	**12.187**	**0.563**
3.469	0.328	2.229	3.039	0.228
1.226	0.116	0.788	1.074	0.081
18.028	**1.764**	**5.257**	**10.462**	**0.603**
7.330	0.381	2.582	2.232	0.234
2.592	0.135	0.913	0.789	0.083

Yellow BF Mz Range (N.m)	Yellow BF Mz max time (s)	Yellow BF Tz Max Value (N.m)	Yellow BF Tz Range (N.m)	Yellow BF COFxy max
31.699	1.337	7.932	11.262	0.483
15.868	1.677	10.488	13.255	0.663
18.369	1.901	4.242	6.065	.
17.691	2.393	5.249	12.444	0.611
12.766	2.118	4.905	7.418	0.463
14.375	2.326	7.017	14.117	0.677
14.887	2.356	9.845	18.147	0.656
15.493	0.930	2.460	4.934	0.750
19.995	0.858	6.010	14.872	0.793
11.148	1.976	8.449	11.795	0.515
8.567	1.130	4.223	6.956	0.642
18.652	3.566	2.841	10.340	0.510
25.080	2.784	9.645	16.941	.
30.535	1.398	11.331	17.686	0.524
23.084	1.728	5.514	8.146	0.503
16.476	1.220	1.244	6.001	0.695
22.047	1.993	9.792	13.096	0.495
19.714	0.980	4.182	11.566	0.560
	.	.		.
14.389	2.772	11.552	22.569	0.346
15.746	2.216	8.250	13.378	0.597
14.352	1.722	6.196	12.891	0.750
21.177	2.317	5.910	13.985	0.556
18.278	**1.895**	**6.694**	**12.176**	**0.589**
5.707	0.686	2.958	4.439	0.114
1.165	0.140	0.604	0.906	0.023
17.403	**2.082**	**6.028**	**11.494**	**0.566**
5.508	0.916	2.917	3.594	0.076
1.947	0.324	1.031	1.271	0.027
21.264	**1.764**	**7.253**	**13.242**	**0.573**
6.718	0.606	2.786	5.231	0.157
2.375	0.214	0.985	1.850	0.056
15.739	**1.860**	**6.722**	**11.638**	**0.626**
3.268	0.562	3.482	4.662	0.095
1.155	0.199	1.231	1.648	0.033

7-IRON

(Relevant to Chapter 5)

Blue Handicap	7 IRON Ball impact Time (s)	Blue Weight Traf Time (s)	Blue FF Fx Range (BW)	Blue FF Fy Range (BW)	Blue FF Fz max value (BW)	Blue FF Fz Range (BW)	Blue FF Fz max time (s)	Blue FF Mz max value (N.m)	Blue FF Mz range (N.m)
1	1.220	0.740	0.199	0.257	0.751	0.508	1.735	18.388	46.101
2	1.170	0.044	0.253	0.412	0.966	0.787	1.794	15.402	36.377
1	1.600	1.633	0.245	0.283	1.200	0.964	3.283	14.786	30.440
2	1.750	0.234	0.173	0.341	0.898	0.823	1.963	18.395	35.615
2	2.020	1.423	0.225	0.399	1.351	1.105	3.023	14.135	38.698
1	1.630	1.073	0.194	0.259	0.905	0.748	3.448	14.665	36.201
3	1.140	0.472	0.243	0.317	1.123	0.986	2.016	5.847	28.227
3	0.590	0.272	0.224	0.205	1.038	0.994	1.965	23.940	48.962
3	1.010	0.578	0.281	0.390	1.001	0.945	1.733	16.559	34.812
2	1.370				.		.	.	
3	0.980	0.607	0.183	0.386	1.323	1.210	1.599	32.922	62.076
1	2.630	0.192	0.206	0.230	1.097	0.886	2.937	21.262	42.453
1	2.610	0.503	0.224	0.285	1.366	1.219	3.268	13.751	35.524
1	1.370	0.870	0.277	0.305	1.090	0.876	2.210	23.888	56.890
2	1.510	0.854	0.162	0.283	0.932	0.624	2.423	8.869	26.191
2	1.150	0.571	0.244	0.305	1.101	0.854	1.872	23.471	56.342
3	1.590	0.093	0.213	0.366	1.024	0.739	2.755	18.469	32.178
3	0.420	0.041	0.171	0.338	0.780	0.629	0.800	14.308	46.241
1	0.001	0.453	0.226	0.382	1.142	0.897	1.725	4.894	34.809
3	1.505	0.538	0.196	0.311	1.097	0.935	2.440	21.058	41.758
2	1.433	0.501	0.234	0.328	1.070	0.882	2.167	13.937	40.906
3	1.452	1.595	0.204	0.315	1.074	0.845	2.724	12.129	32.981
2	1.094	0.500	0.219	0.327	1.086	0.915	1.823	25.249	53.589
1	1.292	0.466	0.211	0.299	1.050	0.837	2.400	18.562	40.917
TOTAL									
MEAN	**1.356**	**0.620**	**0.218**	**0.318**	**1.064**	**0.879**	**2.265**	**17.169**	**40.795**
SD	0.583	0.092	0.031	0.054	0.156	0.170	0.649	6.434	9.607
SE	0.119	0.019	0.006	0.011	0.032	0.035	0.132	1.313	1.961
	Low Handicap								
Mean	**1.544**	**0.741**	**0.223**	**0.288**	**1.075**	**0.867**	**2.626**	**16.274**	**40.417**
SD	0.837	0.018	0.027	0.045	0.185	0.199	0.702	5.772	8.287
SE	0.296	0.006	0.010	0.016	0.065	0.071	0.248	2.041	2.930
	Medium Handicap								
Mean	**1.437**	**0.589**	**0.216**	**0.342**	**1.057**	**0.856**	**2.152**	**17.065**	**41.102**
SD	0.320	0.261	0.035	0.047	0.152	0.145	0.444	5.746	10.558
SE	0.113	0.092	0.012	0.017	0.054	0.051	0.157	2.031	3.733
	High Handicap								
Mean	**1.086**	**0.525**	**0.214**	**0.328**	**1.057**	**0.910**	**2.004**	**18.154**	**40.904**
SD	0.426	0.040	0.035	0.059	0.150	0.176	0.650	8.152	11.207
SE	0.151	0.014	0.012	0.021	0.053	0.062	0.230	2.882	3.962

Green Handicap	7 IRON Ball impact Time (s)	Green Weight Traf Time (s)	Green FF Fx Range (BW)	Green FF Fy Range (BW)	Green FF Fz max value (BW)	Green FF Fz Range (BW)	Green FF Fz max time (s)	Green BF Mz max value (N.m)	Green FF Mz range (N.m)
	1.260	0.784	0.212	0.244	0.799	0.561	1.980	18.592	43.073
	1.220	0.275	0.194	0.335	1.066	0.913	1.679	8.720	36.212
	1.670	0.654	0.248	0.276	1.128	0.882	2.368	20.131	43.165
	2.210	2.019	0.168	0.353	0.826	0.750	2.749	20.884	38.979
	1.110	0.435	0.225	0.377	1.328	1.088	1.822	15.661	38.254
	1.400	0.708	0.192	0.273	0.919	0.764	2.832	13.930	35.201
	1.640	0.354	0.250	0.335	1.104	0.954	2.700	8.354	25.739
	7.710	0.325	0.234	0.291	0.988	0.942	1.381	34.290	59.603
	0.870	0.027	0.335	0.415	0.996	0.963	0.913	11.311	27.158
	1.340	0.215	0.236	0.370	1.572	1.375	1.930	14.342	44.628
	1.040	0.376	0.190	0.348	1.290	1.184	1.712	23.530	49.107
	2.580	1.335	0.211	0.249	1.258	1.032	3.312	23.099	45.244
	2.400	0.591	0.209	0.281	1.315	1.174	2.988	12.403	35.355
	4.950	0.823	0.287	0.296	1.206	0.981	1.999	26.398	64.580
	1.500	0.127	0.153	0.301	0.996	0.685	2.149	10.749	28.800
	1.330	0.294	0.239	0.300	1.020	0.844	1.605	30.086	52.630
	1.700	1.888	0.235	0.324	0.972	0.741	2.478	20.767	32.526
	0.250	0.459	0.222	0.294	1.134	0.921	2.185	19.909	45.341
	0.021	0.693	0.212	0.306	1.079	0.807	1.749	9.742	45.551
	2.760	0.402	0.198	0.316	1.065	0.913	2.243	20.437	40.728
	1.848	0.462	0.253	0.322	1.157	0.972	1.973	21.077	45.535
	1.390	0.468	0.206	0.309	1.142	0.924	2.354	13.655	37.010
	1.995	0.335	0.231	0.315	1.137	0.966	1.957	21.452	46.354
	2.556	0.469	0.216	0.299	1.075	0.863	2.174	19.954	42.876
TOTAL									
MEAN	**1.948**	**0.605**	**0.223**	**0.314**	**1.107**	**0.925**	**2.135**	**18.311**	**41.819**
SD	1.561	0.056	0.037	0.040	0.169	0.173	0.538	6.666	9.280
SE	0.319	0.012	0.008	0.008	0.035	0.035	0.110	1.361	1.894
	Low Handicap								
Mean	**2.105**	**0.757**	**0.223**	**0.278**	**1.097**	**0.883**	**2.425**	**18.031**	**44.381**
SD	1.432	0.067	0.030	0.023	0.172	0.185	0.557	5.623	9.113
SE	0.506	0.024	0.011	0.008	0.061	0.066	0.197	1.988	3.222
	Medium Handicap								
Mean	**1.569**	**0.520**	**0.212**	**0.334**	**1.138**	**0.949**	**1.983**	**17.871**	**41.424**
SD	0.399	0.018	0.037	0.030	0.227	0.215	0.354	6.899	7.364
SE	0.141	0.007	0.013	0.011	0.080	0.076	0.125	2.439	2.604
	High Handicap								
Mean	**2.170**	**0.537**	**0.234**	**0.329**	**1.087**	**0.943**	**1.996**	**19.032**	**39.652**
SD	2.354	0.017	0.046	0.040	0.106	0.120	0.608	8.118	11.516
SE	0.832	0.006	0.016	0.014	0.037	0.043	0.215	2.870	4.072

Red Handicap	7 IRON Ball impact Time (s)	Red Weight Traf Time (s)	Red FF Fx Range (BW)	Red FF Fy Range (BW)	Red FF Fz max value (BW)	Red FF Fz Range (BW)	Red FF Fz max time (s)	Red FF Mz max value (N.m)	Red FF Mz range (N.m)
	1.380	0.400	0.212	0.274	0.919	0.715	1.949	30.059	63.666
	1.170	0.952	0.197	0.271	1.009	0.893	2.053	17.490	39.685
	1.630	0.684	0.253	0.270	1.110	0.868	2.404	15.318	32.216
	1.920	1.129	0.182	0.342	0.848	0.762	2.884	20.791	36.103
	1.130	0.426	0.222	0.403	1.260	1.043	1.927	14.226	32.819
	2.000	0.914	0.196	0.279	0.924	0.758	2.963	18.118	38.857
	1.250	0.242	0.280	0.355	1.053	0.931	2.260	13.151	27.852
	7.350	0.506	0.232	0.272	1.030	0.981	1.466	17.925	39.151
	0.900	0.640	0.355	0.422	1.015	0.960	2.117	11.366	22.958
	1.290	0.209	0.229	0.356	1.587	1.390	1.924	14.042	41.334
	0.760	0.620	0.186	0.366	1.268	1.173	1.337	30.185	59.280
	2.780	1.867	0.246	0.270	1.308	1.072	3.596	14.727	38.325
	2.200	0.572	0.201	0.328	1.293	1.152	2.802	13.824	36.897
	6.230	0.715	0.272	0.281	1.065	0.819	2.271	17.377	56.914
	1.330	0.141	0.256	0.322	0.974	0.737	2.010	17.766	41.013
	1.210	0.516	0.182	0.333	1.152	0.946	1.719	18.308	48.608
	1.750	0.716	0.242	0.294	1.103	0.889	2.316	23.651	47.196
	0.450	0.601	0.175	0.344	0.806	0.632	2.159	19.008	40.929
	1.480	0.342	0.233	0.345	1.302	1.104	2.683	10.504	44.594
	0.920	0.176	0.197	0.301	0.886	0.606	2.517	12.266	26.718
	2.117	0.461	0.256	0.342	1.101	0.912	1.965	13.052	37.309
	1.675	0.499	0.212	0.320	1.197	1.005	2.299	13.484	38.815
	1.803	0.312	0.229	0.330	1.038	0.851	1.877	16.729	41.730
	2.801	0.689	0.230	0.307	1.136	0.949	2.189	14.300	39.294
TOTAL									
MEAN	**1.980**	**0.597**	**0.228**	**0.322**	**1.099**	**0.923**	**2.237**	**16.986**	**40.511**
SD	1.598	0.098	0.040	0.042	0.178	0.181	0.497	5.077	9.625
SE	0.326	0.020	0.008	0.009	0.036	0.037	0.102	1.036	1.965
	Low Handicap								
Mean	**2.563**	**0.773**	**0.230**	**0.294**	**1.132**	**0.930**	**2.607**	**16.778**	**43.845**
SD	1.579	0.194	0.026	0.029	0.160	0.166	0.522	5.845	10.849
SE	0.558	0.069	0.009	0.010	0.057	0.059	0.185	2.066	3.836
	Medium Handicap								
Mean	**1.496**	**0.518**	**0.219**	**0.337**	**1.121**	**0.942**	**2.045**	**16.550**	**39.825**
SD	0.388	0.088	0.030	0.037	0.225	0.206	0.354	2.602	4.686
SE	0.137	0.031	0.010	0.013	0.079	0.073	0.125	0.920	1.657
	High Handicap								
Mean	**1.882**	**0.500**	**0.235**	**0.334**	**1.045**	**0.897**	**2.059**	**17.629**	**37.862**
SD	2.254	0.104	0.059	0.048	0.151	0.191	0.424	6.559	11.978
SE	0.797	0.037	0.021	0.017	0.053	0.068	0.150	2.319	4.235

Black Handicap	7 IRON Ball impact Time (s)	Black Weight Traf Time (s)	Black FF Fx Range (BW)	Black FF Fy Range (BW)	Black FF Fz max value (BW)	Black FF Fz Range (BW)	Black FF Fz max time (s)	Black FF Mz max value (N.m)	Black FF Mz range (N.m)
	1.340	0.137	0.199	0.271	0.912	0.679	1.725	19.262	44.331
	0.860	0.381	0.210	0.349	0.890	0.711	1.830	20.815	41.213
	1.590	0.455	0.241	0.277	1.165	0.915	1.912	17.394	32.146
	1.300	0.486	0.188	0.305	0.882	0.816	3.007	18.232	35.354
	1.060	1.600	0.231	0.383	1.449	1.196	2.022	17.798	42.245
	1.510	0.609	0.202	0.256	0.885	0.742	3.129	22.315	41.610
	1.150	1.988	0.233	0.288	1.060	0.904	2.454	12.262	37.019
	0.380	0.057	0.241	0.286	1.004	0.956	2.371	15.014	38.475
	0.310	0.049	0.306	0.398	0.983	0.925	1.544	18.067	35.847
	1.450	0.496	0.211	0.372	1.411	1.198	2.878	19.531	45.473
	0.550	0.066	0.196	0.355	1.425	1.318	1.564	16.434	45.793
	2.580	1.263	0.201	0.222	1.096	0.881	3.739	19.912	32.878
	1.880	1.513	0.237	0.321	1.359	1.216	2.892	12.423	36.359
	0.970	0.944	0.275	0.264	1.107	0.862	2.394	13.675	38.985
	1.420	0.143	0.237	0.328	0.947	0.720	2.243	17.611	41.570
	0.710	0.304	0.173	0.299	1.129	0.924	1.782	16.636	39.146
	1.090	0.145	0.250	0.341	1.184	0.971	2.584	14.830	33.036
	0.500	0.057	0.187	0.349	0.786	0.575	1.150	19.988	41.539
	0.700	0.261	0.231	0.336	1.196	0.966	1.682	10.404	41.190
	1.800	1.407	0.214	0.281	0.811	0.575	2.833	19.796	39.659
	1.158	0.199	0.223	0.314	1.084	0.902	2.167	11.770	32.806
	1.148	0.727	0.224	0.316	1.093	0.914	2.189	19.795	40.630
	1.163	0.744	0.225	0.315	1.103	0.924	2.207	11.794	32.650
	1.141	0.759	0.224	0.316	1.100	0.924	2.222	16.814	37.976
TOTAL									
MEAN	**1.157**	**0.616**	**0.223**	**0.314**	**1.086**	**0.905**	**2.272**	**16.774**	**38.664**
SD	0.517	0.016	0.029	0.042	0.188	0.190	0.598	3.307	4.124
SE	0.106	0.003	0.006	0.009	0.038	0.039	0.122	0.675	0.842
	Low Handicap								
Mean	**1.464**	**0.743**	**0.226**	**0.283**	**1.102**	**0.898**	**2.462**	**16.525**	**38.184**
SD	0.584	0.250	0.026	0.039	0.152	0.160	0.735	4.066	4.262
SE	0.206	0.088	0.009	0.014	0.054	0.057	0.260	1.438	1.507
	Medium Handicap								
Mean	**1.140**	**0.544**	**0.212**	**0.333**	**1.112**	**0.924**	**2.267**	**16.773**	**38.807**
SD	0.259	0.222	0.022	0.031	0.218	0.188	0.451	3.331	4.715
SE	0.092	0.079	0.008	0.011	0.077	0.067	0.159	1.178	1.667
	High Handicap								
Mean	**0.866**	**0.562**	**0.231**	**0.327**	**1.043**	**0.892**	**2.086**	**17.023**	**39.000**
SD	0.516	0.036	0.037	0.041	0.205	0.237	0.595	2.856	3.880
SE	0.182	0.013	0.013	0.015	0.072	0.084	0.210	1.010	1.372

Yellow Handicap	7 IRON Ball impact Time (s)	Yellow Weight Traf Time (s)	Yellow FF Fx Range (BW)	Yellow FF Fy Range (BW)	Yellow FF Fz max value (BW)	Yellow FF Fz Range (BW)	Yellow FF Fz max time (s)	Yellow FF Mz max value (N.m)	Yellow FF Mz range (N.m)
	1.200	0.818	0.214	0.214	0.873	0.576	2.110	12.353	33.553
	1.200	0.277	0.243	0.330	0.916	0.791	1.897	15.728	42.810
	2.000	0.353	0.229	0.279	1.033	0.825	2.411	23.806	45.146
	1.960	0.386	0.197	0.318	0.948	0.891	2.728	13.227	30.907
	1.170	0.433	0.232	0.375	1.407	1.176	1.959	17.736	45.385
	2.040	1.554	0.201	0.274	0.917	0.759	3.210	14.337	35.871
	1.370	0.662	0.213	0.324	1.047	0.904	2.699	15.257	38.743
	0.570	0.640	0.245	0.297	0.981	0.933	1.527	19.262	49.238
	1.030	0.395	0.329	0.382	0.955	0.915	1.779	20.889	35.375
	1.510	0.191	0.222	0.360	1.406	1.180	2.085	12.681	44.672
	4.090	0.599	0.180	0.341	1.406	1.303	1.331	31.233	59.773
	2.530	0.779	0.255	0.227	1.227	1.011	2.438	12.236	33.187
	2.500	0.583	0.202	0.346	1.292	1.156	3.120	19.174	51.347
	1.470	0.844	0.254	0.288	1.094	0.872	2.344	35.667	62.061
	1.150	1.290	0.161	0.300	0.928	0.614	2.397	7.281	22.773
	1.160	0.509	0.261	0.288	1.096	0.884	1.780	25.698	55.189
	1.910	0.443	0.237	0.348	1.005	0.787	2.703	17.589	33.129
	0.400	0.893	0.166	0.339	0.804	0.539	0.950	7.246	25.559
	2.020				.		.	.	
	0.015	0.342	0.231	0.326	0.868	0.464	3.023	11.899	24.800
	1.565	0.539	0.219	0.314	1.063	0.873	2.355	18.595	42.606
	1.583	0.524	0.220	0.319	1.073	0.888	2.367	18.923	43.083
	1.602	0.537	0.220	0.318	1.082	0.893	2.392	19.091	43.097
	1.582	0.534	0.219	0.320	1.084	0.897	2.378	18.843	42.989
TOTAL									
MEAN	**1.568**	**0.614**	**0.224**	**0.314**	**1.065**	**0.875**	**2.260**	**17.772**	**40.926**
SD	0.806	0.041	0.035	0.041	0.175	0.207	0.557	6.754	10.482
SE	0.164	0.008	0.007	0.008	0.036	0.042	0.114	1.379	2.140
	Low Handicap								
Mean	**1.918**	**0.781**	**0.225**	**0.278**	**1.074**	**0.871**	**2.573**	**19.488**	**43.451**
SD	0.474	0.011	0.023	0.047	0.152	0.184	0.419	8.276	10.587
SE	0.168	0.004	0.008	0.017	0.054	0.065	0.148	2.926	3.743
	Medium Handicap								
Mean	**1.415**	**0.520**	**0.219**	**0.325**	**1.106**	**0.913**	**2.199**	**16.255**	**40.930**
SD	0.294	0.068	0.030	0.029	0.198	0.188	0.320	5.446	9.844
SE	0.104	0.024	0.011	0.010	0.070	0.067	0.113	1.926	3.480
	High Handicap								
Mean	**1.371**	**0.562**	**0.227**	**0.335**	**1.018**	**0.842**	**2.047**	**17.787**	**38.713**
SD	1.269	0.128	0.049	0.025	0.180	0.259	0.753	7.031	11.846
SE	0.449	0.045	0.017	0.009	0.064	0.092	0.266	2.486	4.188

Blue FF Mz max time (s)	Blue FF Tz max value (N.m)	Blue FF Tz Range (N.m)	Blue FF COFxy max	Blue BF Fx Range (BW)	Blue BF Fy Range (BW)	Blue BF Fz max value (BW)	Blue BF Fz Range (BW)	Blue BF Fz max time (s)
1.022	20.279	37.742	0.386	0.131	0.204	0.801	0.457	0.996
1.748	13.543	30.438	0.785	0.193	0.372	0.853	0.603	1.750
1.607	20.827	39.403	0.449	0.150	0.269	0.736	0.609	1.650
2.453	18.767	29.736	0.569	0.171	0.319	0.978	0.811	1.729
2.478	13.958	38.675	0.412	0.225	0.276	0.745	0.618	1.600
1.990	16.596	35.779	0.642	0.137	0.243	0.810	0.716	2.375
1.789	14.881	47.227	0.743	0.325	0.235	0.898	0.831	1.544
1.705	33.465	61.609	0.688	0.175	0.220	0.952	0.854	1.693
1.303	18.137	36.972	0.787	0.236	0.227	0.868	0.802	1.156
2.158	.		.			.		.
0.836	21.202	44.550	0.588	0.231	0.446	0.910	0.829	0.992
2.264	14.818	32.596	0.357	0.185	0.179	0.798	0.678	2.744
3.186	16.978	44.493	0.845	0.248	0.236	0.798	0.759	2.765
1.167	21.664	56.601	0.575	0.199	0.298	0.813	0.744	1.340
1.212	14.115	31.453	0.809	0.152	0.353	0.891	0.821	1.569
1.560	17.870	49.161	0.610	0.212	0.236	0.746	0.516	1.301
2.042	17.927	36.756	0.371	0.158	0.307	0.645	0.343	2.662
0.830	27.243	48.690	0.543	0.164	0.328	0.845	0.492	0.759
0.713	12.877	42.971	0.567	0.191	0.312	0.762	0.603	1.272
2.419	20.409	41.433	0.928	0.178	0.314	0.862	0.736	1.902
1.600	18.948	43.782	0.547	0.188	0.257	0.829	0.669	1.667
2.244	15.699	38.290	0.587	0.163	0.290	0.781	0.648	1.129
1.348	20.545	47.943	0.664	0.203	0.310	0.846	0.691	1.323
1.589	18.692	41.528	0.840	0.175	0.271	0.813	0.661	1.934
1.719	**18.671**	**41.645**	**0.621**	**0.191**	**0.283**	**0.825**	**0.674**	**1.646**
0.616	4.627	7.965	0.163	0.043	0.060	0.075	0.133	0.557
0.026	0.945	1.626	0.033	0.009	0.012	0.015	0.027	0.114
1.692	**17.841**	**41.389**	**0.583**	**0.177**	**0.251**	**0.791**	**0.653**	**1.885**
0.788	3.077	7.266	0.188	0.038	0.045	0.028	0.098	0.684
0.099	1.088	2.569	0.066	0.014	0.016	0.010	0.035	0.242
1.820	**16.821**	**38.741**	**0.628**	**0.192**	**0.303**	**0.841**	**0.676**	**1.563**
0.487	2.873	8.385	0.139	0.025	0.050	0.082	0.111	0.183
0.061	1.016	2.965	0.049	0.009	0.018	0.029	0.039	0.065
1.646	**21.120**	**44.441**	**0.654**	**0.204**	**0.296**	**0.845**	**0.692**	**1.479**
0.607	6.300	8.301	0.170	0.058	0.074	0.095	0.186	0.611
0.076	2.227	2.935	0.060	0.020	0.026	0.034	0.066	0.216

Green FF Mz max time (s)	Green FF Tz max value (N.m)	Green FF Tz Range (N.m)	Green FF COFxy max	Green BF Fx Range (BW)	Green BF Fy Range (BW)	Green BF Fz max value (BW)	Green BF Fz Range (BW)	Green BF Fz max time (s)
1.537	22.108	39.275	0.361	0.143	0.196	0.804	0.494	1.196
1.636	10.858	38.171	0.643	0.209	0.311	0.774	0.605	1.404
1.961	15.206	33.380	0.453	0.148	0.247	0.741	0.558	1.714
2.485	18.829	31.847	0.555	0.149	0.281	0.974	0.810	0.730
1.632	15.881	39.248	0.425	0.248	0.251	0.726	0.625	1.388
0.958	17.522	37.591	0.583	0.136	0.248	0.821	0.730	2.124
2.294	17.216	45.945	0.747	0.285	0.202	0.856	0.795	2.346
1.222	38.441	66.731	0.699	0.195	0.233	0.993	0.840	1.056
0.997	25.529	45.275	0.785	0.283	0.220	0.815	0.750	0.886
1.600	12.775	38.905	0.726	0.202	0.206	0.683	0.615	1.715
1.596	20.123	42.062	0.627	0.236	0.392	0.940	0.812	1.336
2.155	13.052	31.211	0.676	0.227	0.193	0.806	0.696	1.977
2.485	17.050	45.539	0.818	0.195	0.249	0.817	0.741	2.397
1.315	21.756	61.221	0.580	0.171	0.298	0.768	0.719	1.175
1.939	15.045	31.140	0.518	0.159	0.369	0.856	0.724	2.021
1.625	21.805	47.969	0.724	0.237	0.216	0.791	0.491	1.311
2.126	20.228	32.239	0.519	0.154	0.264	0.742	0.395	0.590
1.841	18.914	46.467	0.660	0.190	0.283	0.808	0.669	1.726
1.304	12.483	44.785	0.548	0.182	0.293	0.793	0.668	1.057
1.975	21.619	41.593	0.826	0.181	0.298	0.887	0.720	1.841
0.193	19.490	45.232	0.626	0.226	0.243	0.821	0.694	1.511
1.430	15.851	38.366	0.619	0.171	0.271	0.785	0.645	1.886
1.774	20.239	47.543	0.660	0.217	0.282	0.842	0.701	1.622
0.751	19.790	41.889	0.542	0.190	0.266	0.835	0.669	1.704
1.618	**18.825**	**42.234**	**0.622**	**0.197**	**0.263**	**0.820**	**0.674**	**1.530**
0.549	5.512	8.603	0.120	0.041	0.050	0.073	0.109	0.481
0.023	1.125	1.756	0.025	0.008	0.010	0.015	0.022	0.098
1.558	**17.371**	**41.861**	**0.570**	**0.174**	**0.249**	**0.798**	**0.659**	**1.668**
0.599	3.682	9.313	0.137	0.031	0.039	0.031	0.088	0.489
0.075	1.302	3.293	0.049	0.011	0.014	0.011	0.031	0.173
1.610	**16.865**	**40.007**	**0.610**	**0.206**	**0.270**	**0.808**	**0.658**	**1.463**
0.645	3.848	6.523	0.104	0.035	0.053	0.088	0.096	0.373
0.081	1.360	2.306	0.037	0.012	0.019	0.031	0.034	0.132
1.685	**22.240**	**44.835**	**0.685**	**0.212**	**0.271**	**0.853**	**0.703**	**1.458**
0.453	7.165	10.016	0.100	0.050	0.059	0.084	0.142	0.591
0.057	2.533	3.541	0.035	0.018	0.021	0.030	0.050	0.209

Red FF Mz max time (s)	Red FF Tz max value (N.m)	Red FF Tz Range (N.m)	Red FF COFxy max	Red BF Fx Range (BW)	Red BF Fy Range (BW)	Red BF Fz max value (BW)	Red BF Fz Range (BW)	Red BF Fz max time (s)
1.250	24.549	41.072	0.428	0.193	0.197	0.791	0.514	1.548
1.554	12.246	35.782	0.716	0.187	0.281	0.846	0.690	1.100
1.735	15.676	35.208	0.491	0.161	0.265	0.750	0.585	1.719
2.501	18.888	32.295	0.635	0.190	0.337	0.957	0.797	1.756
1.437	16.567	39.403	0.412	0.251	0.228	0.766	0.641	1.502
1.328	15.762	36.233	0.675	0.159	0.248	0.815	0.693	2.049
2.191	14.834	43.527	0.845	0.301	0.230	0.887	0.798	2.018
0.913	37.501	64.293	0.645	0.176	0.255	0.988	0.800	0.960
1.169	19.968	35.522	0.965	0.254	0.256	0.857	0.699	1.477
0.964	12.266	36.704	0.718	0.177	0.213	0.655	0.550	1.715
0.644	21.384	45.406	0.534	0.211	0.437	0.947	0.849	0.717
3.026	12.338	36.485	0.397	0.252	0.193	0.745	0.580	1.729
2.671	17.082	44.081	0.832	0.202	0.250	0.822	0.759	2.230
1.358	20.256	56.459	0.505	0.157	0.271	0.737	0.688	1.556
2.002	16.627	32.183	0.622	0.165	0.404	0.908	0.747	1.869
1.616	17.894	52.044	0.668	0.280	0.228	0.774	0.548	1.203
2.180	18.424	37.624	0.522	0.214	0.244	0.729	0.612	1.600
1.504	21.788	37.000	0.642	0.132	0.326	0.812	0.596	1.558
1.094	15.247	47.908	0.642	0.193	0.301	0.805	0.688	2.340
2.077	16.277	35.457	0.577	0.289	0.256	0.940	0.718	2.341
1.685	18.823	43.507	0.598	0.221	0.250	0.847	0.675	1.504
2.433	15.901	39.122	0.668	0.185	0.277	0.789	0.675	1.800
1.717	19.427	45.670	0.628	0.228	0.291	0.850	0.684	1.566
1.961	19.827	43.667	0.571	0.204	0.275	0.837	0.684	1.500
1.709	**18.315**	**41.527**	**0.622**	**0.208**	**0.271**	**0.827**	**0.678**	**1.640**
0.596	5.111	7.760	0.136	0.044	0.058	0.081	0.088	0.399
0.025	1.043	1.584	0.028	0.009	0.012	0.017	0.018	0.081
1.803	**17.592**	**42.639**	**0.568**	**0.190**	**0.250**	**0.788**	**0.649**	**1.834**
0.708	3.796	7.156	0.144	0.032	0.038	0.039	0.081	0.328
0.089	1.342	2.530	0.051	0.011	0.013	0.014	0.028	0.116
1.684	**16.592**	**39.698**	**0.624**	**0.212**	**0.279**	**0.825**	**0.666**	**1.527**
0.443	2.868	6.951	0.096	0.040	0.065	0.093	0.087	0.266
0.055	1.014	2.458	0.034	0.014	0.023	0.033	0.031	0.094
1.639	**20.760**	**42.244**	**0.675**	**0.220**	**0.285**	**0.869**	**0.718**	**1.559**
0.673	7.237	9.619	0.155	0.058	0.068	0.089	0.092	0.529
0.084	2.559	3.401	0.055	0.020	0.024	0.031	0.032	0.187

Black FF Mz max time (s)	Black FF Tz max value (N.m)	Black FF Tz Range (N.m)	Black FF COFxy max	Black BF Fx Range (BW)	Black BF Fy Range (BW)	Black BF Fz max value (BW)	Black BF Fz Range (BW)	Black BF Fz max time (s)
1.111	19.015	34.519	0.373	0.193	0.092	0.653	0.471	1.587
0.867	11.139	35.211	0.663	0.219	0.206	0.786	0.667	1.450
1.266	14.594	32.155	0.413	0.178	0.215	0.678	0.542	1.457
2.521	18.839	31.836	0.642	0.151	0.181	0.731	0.667	2.521
1.465	14.865	41.590	0.374	0.229	0.243	0.846	0.656	0.422
1.491	15.963	33.354	0.700	0.191	0.337	0.783	0.763	2.520
1.251	13.775	39.180	0.614	0.243	0.147	0.137	0.071	0.466
0.877	38.843	66.139	0.686	0.236	0.186	0.834	0.764	2.314
1.160	18.828	37.153	0.885	0.243	0.051	1.312	1.237	1.496
0.506	13.893	37.123	0.653	0.210	0.122	0.661	0.241	2.382
1.034	19.588	43.778	0.501	0.229	0.310	1.008	0.983	1.498
2.544	13.575	29.470	0.716	0.207	0.200	0.681	0.530	2.476
2.260	17.523	45.495	0.897	0.177	0.429	0.872	0.842	1.378
1.284	20.940	53.837	0.510	0.168	0.481	0.726	0.673	1.451
0.866	16.605	34.635	0.574	0.198	0.442	0.923	0.857	2.100
1.316	18.714	45.851	0.674	0.269	0.692	0.896	0.524	1.478
1.515	17.829	36.733	0.556	0.182	0.251	0.141	0.073	2.439
0.803	23.617	43.946	0.482	0.140	0.146	1.008	0.763	1.093
0.960	13.360	43.352	0.577	0.181	0.205	0.747	0.650	1.421
1.737	15.767	34.543	0.668	0.277	0.315	1.331	1.269	1.426
1.342	17.864	39.995	0.593	0.164	0.272	0.748	0.703	1.968
2.531	17.806	40.269	0.604	0.165	0.269	0.633	0.152	1.462
1.377	18.139	40.522	0.601	0.165	0.296	0.766	0.717	1.462
1.383	18.317	40.940	0.610	0.167	0.037	0.643	0.492	1.463
1.394	**17.892**	**40.068**	**0.607**	**0.199**	**0.255**	**0.773**	**0.638**	**1.655**
0.562	5.257	7.820	0.130	0.037	0.147	0.269	0.305	0.582
0.024	1.073	1.596	0.027	0.008	0.030	0.055	0.062	0.119
1.537	**16.661**	**39.140**	**0.599**	**0.183**	**0.250**	**0.723**	**0.620**	**1.719**
0.562	2.739	8.233	0.172	0.014	0.155	0.077	0.134	0.484
0.080	0.968	2.911	0.061	0.005	0.055	0.027	0.047	0.171
1.282	**16.257**	**38.345**	**0.597**	**0.201**	**0.307**	**0.795**	**0.629**	**1.723**
0.601	2.743	4.500	0.097	0.040	0.182	0.088	0.181	0.673
0.075	0.970	1.591	0.034	0.014	0.064	0.031	0.064	0.238
1.363	**20.757**	**42.717**	**0.625**	**0.214**	**0.209**	**0.800**	**0.664**	**1.524**
0.566	7.850	10.023	0.128	0.047	0.093	0.468	0.504	0.630
0.071	2.775	3.544	0.045	0.017	0.033	0.166	0.178	0.223

Yellow FF Mz max time (s)	Yellow FF Tz max value (N.m)	Yellow FF Tz Range (N.m)	Yellow FF COFxy max	Yellow BF Fx Range (BW)	Yellow BF Fy Range (BW)	Yellow BF Fz max value (BW)	Yellow BF Fz Range (BW)	Yellow BF Fz max time (s)
1.431	18.420	33.697	0.356	0.167	0.174	0.718	0.470	1.292
1.638	18.533	41.062	0.673	0.206	0.327	0.817	0.622	1.620
2.070	16.750	32.499	0.614	0.132	0.269	0.771	0.565	2.057
3.433	13.747	25.864	1.600	0.146	0.267	0.775	0.687	2.342
1.425	14.931	39.846	0.417	0.239	0.262	0.741	0.652	1.527
2.015	16.895	35.878	0.623	0.153	0.239	0.816	0.733	1.656
2.128	13.526	33.162	1.328	0.186	0.274	0.787	0.673	2.036
0.829	38.451	66.223	0.693	0.165	0.292	0.982	0.760	0.887
1.246	21.428	38.262	1.086	0.300	0.241	0.795	0.691	1.385
0.368	14.143	34.640	0.672	0.170	0.220	0.844	0.747	1.894
0.687	17.500	38.954	0.550	0.211	0.421	0.921	0.835	0.732
3.202	12.731	32.482	0.420	0.249	0.143	0.756	0.674	1.659
2.668	17.343	50.575	0.804	0.216	0.277	0.842	0.784	2.537
1.844	22.035	55.683	0.439	0.186	0.285	0.808	0.727	1.500
0.852	15.022	32.039	0.481	0.164	0.321	0.798	0.658	1.107
1.546	18.668	45.570	0.637	0.230	0.237	0.954	0.707	1.271
1.419	20.038	41.273	0.512	0.196	0.305	0.708	0.564	2.260
0.860	18.725	40.940	0.492	0.123	0.330	0.747	0.424	0.057
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2.705	15.068	31.269	0.361	0.251	0.299	0.955	0.772	2.681
1.703	17.347	38.713	0.777	0.193	0.273	0.816	0.670	1.816
1.718	17.290	38.977	0.799	0.195	0.278	0.821	0.680	1.843
2.198	17.751	39.393	0.505	0.195	0.275	0.822	0.683	1.855
1.465	17.804	39.756	0.816	0.198	0.276	0.824	0.689	1.845
1.715	**18.006**	**39.424**	**0.681**	**0.194**	**0.273**	**0.818**	**0.673**	**1.646**
0.780	5.063	8.697	0.305	0.041	0.055	0.073	0.095	0.598
0.039	1.034	1.775	0.062	0.008	0.011	0.015	0.019	0.122
2.099	**17.425**	**40.081**	**0.582**	**0.186**	**0.238**	**0.791**	**0.663**	**1.792**
0.641	2.743	9.375	0.185	0.040	0.057	0.044	0.109	0.408
0.107	0.970	3.314	0.065	0.014	0.020	0.016	0.039	0.144
1.645	**16.268**	**37.141**	**0.720**	**0.193**	**0.273**	**0.821**	**0.678**	**1.679**
0.912	2.017	6.103	0.375	0.032	0.037	0.062	0.038	0.389
0.114	0.713	2.158	0.133	0.011	0.013	0.022	0.013	0.137
1.449	**20.253**	**41.133**	**0.728**	**0.203**	**0.305**	**0.839**	**0.675**	**1.485**
0.704	7.778	10.744	0.330	0.054	0.054	0.101	0.130	0.881
0.088	2.750	3.799	0.117	0.019	0.019	0.036	0.046	0.312

Blue BF Mz max value (N.m)	Blue BF Mz Range (N.m)	Blue BF Mz max time (s)	Blue BF Tz Max Value (N.m)	Blue BF Tz Range (N.m)	Blue BF COFxy max
16.933	21.586	1.474	6.549	14.123	0.346
10.590	23.842	1.779	9.657	18.438	0.438
12.481	22.916	1.766	9.665	18.233	1.324
5.689	11.358	2.165	4.987	10.028	0.433
6.712	12.362	2.796	5.314	8.253	0.754
5.870	9.584	2.414	4.955	11.683	0.405
14.861	29.540	1.632	3.134	4.724	0.840
6.379	12.686	1.561	5.091	6.923	0.463
5.633	15.052	1.221	4.260	11.822	1.075
4.789	12.055	1.373	3.105	5.906	0.635
4.115	11.585	3.155	3.887	10.457	0.445
8.614	19.466	2.750	9.455	11.808	1.026
14.052	17.931	1.639	9.263	18.361	0.552
4.658	17.597	1.562	3.814	6.826	0.407
4.418	13.082	1.641	1.795	10.011	0.534
8.050	20.625	2.429	8.611	19.460	0.521
0.584	6.916	0.829	6.275	21.202	0.458
3.116	11.944	1.667	6.324	9.350	0.559
6.028	15.296	1.973	6.653	10.968	0.781
5.919	12.821	1.880	5.132	13.351	0.636
5.196	14.978	2.164	7.603	12.797	0.624
6.913	15.261	1.515	5.037	11.862	0.633
4.652	13.822	2.042	5.477	11.061	0.672
7.228	**15.752**	**1.888**	**5.915**	**12.072**	**0.633**
4.008	5.263	0.546	2.251	4.492	0.243
0.818	1.074	0.111	0.459	0.917	0.050
8.729	**16.104**	**2.113**	**6.947**	**13.135**	**0.666**
5.173	5.022	0.602	2.239	3.463	0.340
1.829	1.776	0.213	0.791	1.224	0.120
6.414	**15.189**	**1.905**	**5.105**	**11.253**	**0.548**
2.066	4.347	0.451	2.360	3.831	0.131
0.730	1.537	0.159	0.834	1.354	0.046
6.440	**15.893**	**1.648**	**5.592**	**11.725**	**0.675**
4.016	6.720	0.523	2.036	6.063	0.213
1.420	2.376	0.185	0.720	2.144	0.075

Total
Weight Transfer Times

Shoe	Low Handicap
Blue	0.741
Green	0.757
Red	0.773
Black	0.743
Yellow	0.781
Mean	**0.76**

Shoe	Medium Handicap
Blue	0.589
Green	0.520
Red	0.518
Black	0.544
Yellow	0.520
Mean	**0.54**

Shoe	High Handicap
Blue	0.525
Green	0.537
Red	0.500
Black	0.562
Yellow	0.562
Mean	**0.54**

Green BF Mz max value (N.m)	Green BF Mz Range (N.m)	Green BF Mz max time (s)	Green BF Tz Max Value (N.m)	Green BF Tz Range (N.m)	Green BF COFxy max
16.067	20.296	1.537	6.863	13.773	0.345
6.797	19.727	1.636	8.267	11.595	0.455
11.280	17.118	1.961	7.850	12.379	0.618
7.248	14.775	2.485	3.470	12.011	0.300
6.690	11.920	1.632	5.175	7.284	0.795
7.264	9.978	2.187	6.676	13.160	0.823
10.810	15.845	2.294	3.374	4.947	0.768
3.706	11.348	1.222	3.641	6.055	0.530
14.026	26.836	0.997	8.474	17.419	.
3.006	12.180	1.600	4.147	13.713	0.760
2.125	8.173	1.596	2.773	5.731	0.543
4.578	18.639	3.103	5.546	16.304	0.456
6.253	14.466	2.485	7.779	9.538	0.772
17.769	21.650	1.315	8.568	16.845	0.508
2.663	15.901	1.939	1.840	5.256	0.493
10.176	15.272	1.625	3.572	5.896	0.519
6.850	7.005	2.126	6.409	11.583	0.448
5.046	12.653	1.841	7.429	11.374	0.573
2.028	8.659	1.304	5.166	9.473	0.846
3.920	11.057	1.975	5.089	8.466	0.514
7.329	15.443	1.752	7.017	13.857	0.612
3.790	10.477	1.940	6.107	11.042	0.691
6.416	12.216	1.774	5.690	9.432	0.571
3.144	11.451	1.908	4.936	9.755	0.636
7.041	**14.295**	**1.843**	**5.661**	**10.704**	**0.590**
4.325	4.715	0.462	1.930	3.669	0.151
0.883	0.962	0.094	0.394	0.749	0.031
8.548	**15.282**	**1.975**	**6.673**	**12.653**	**0.626**
5.897	4.894	0.616	1.352	2.945	0.181
2.085	1.730	0.218	0.478	1.041	0.064
6.291	**14.679**	**1.805**	**4.897**	**9.880**	**0.563**
2.434	2.614	0.297	2.079	3.427	0.162
0.861	0.924	0.105	0.735	1.211	0.057
6.284	**12.924**	**1.749**	**5.412**	**9.577**	**0.581**
4.106	6.230	0.447	2.045	4.154	0.111
1.452	2.203	0.158	0.723	1.468	0.039

Red BF Mz max value (N.m)	Red BF Mz Range (N.m)	Red BF Mz max time (s)	Red BF Tz Max Value (N.m)	Red BF Tz Range (N.m)	Red BF COFxy max
12.976	19.694	1.669	6.983	12.364	0.692
3.277	7.882	2.256	6.802	10.380	0.684
15.780	20.520	1.908	9.477	12.091	0.717
7.165	15.512	2.214	4.342	12.314	0.461
12.629	20.024	1.866	4.791	7.136	0.793
7.300	13.300	2.339	5.756	12.987	0.728
13.203	26.715	2.169	1.412	6.276	0.878
10.258	21.699	1.113	2.781	6.262	0.428
12.858	36.478	1.172	7.646	20.544	0.705
1.661	10.546	1.575	4.569	7.451	0.518
3.142	11.558	1.118	3.873	6.746	0.584
3.256	16.177	3.471	3.895	17.592	0.579
3.843	11.405	2.275	11.116	13.532	0.596
15.603	17.644	1.743	11.800	19.441	0.488
0.028	9.144	1.496	4.559	9.127	0.449
3.596	9.323	1.136	0.298	5.728	0.586
7.508	15.300	1.961	5.623	8.575	0.544
2.208	13.395	1.322	3.276	14.952	0.542
-2.038	1.611	1.508	3.035	4.325	0.636
5.124	14.431	1.939	6.453	17.276	0.435
13.358	23.840	1.785	5.284	15.636	0.615
3.050	10.218	1.859	5.776	9.333	0.623
10.479	19.011	1.571	4.519	12.786	0.585
5.395	14.628	1.889	4.196	10.253	0.542
7.152	**15.836**	**1.806**	**5.344**	**11.379**	**0.600**
5.201	7.154	0.519	2.717	4.535	0.115
1.062	1.460	0.106	0.555	0.926	0.023
7.764	**14.372**	**2.100**	**7.032**	**12.823**	**0.622**
6.442	6.011	0.623	3.399	4.577	0.087
2.278	2.125	0.220	1.202	1.618	0.031
6.524	**14.410**	**1.737**	**4.395**	**10.070**	**0.586**
5.141	6.023	0.376	1.836	3.353	0.115
1.818	2.130	0.133	0.649	1.185	0.041
7.169	**18.724**	**1.582**	**4.605**	**11.245**	**0.592**
4.479	9.025	0.441	2.101	5.569	0.147
1.583	3.191	0.156	0.743	1.969	0.052

Black BF Mz max value (N.m)	Black BF Mz Range (N.m)	Black BF Mz max time (s)	Black BF Tz Max Value (N.m)	Black BF Tz Range (N.m)	Black BF COFxy max
11.757	19.499	1.383	6.232	11.732	0.468
1.072	5.887	0.737	9.216	15.236	0.567
12.590	20.476	2.593	5.523	8.549	0.733
7.635	16.333	3.757	3.334	8.458	0.451
8.620	12.778	1.273	5.736	7.197	0.727
6.164	13.160	2.610	4.532	11.831	0.371
12.819	20.233	1.624	5.040	6.217	0.722
14.165	17.610	2.489	5.356	8.182	0.463
7.085	16.064	1.478	7.353	14.968	0.796
3.768	6.767	1.538	5.449	8.523	0.473
1.855	6.606	1.154	2.117	4.658	0.555
6.256	15.966	1.835	3.404	16.351	0.400
3.380	11.284	2.496	9.562	11.762	0.821
10.628	21.247	2.238	7.573	14.797	0.682
3.695	12.694	1.031	2.990	9.604	0.430
2.266	10.175	0.668	1.709	7.615	0.525
4.446	8.645	1.465	7.283	8.980	0.435
1.056	7.218	1.648	4.102	13.881	0.494
6.387	16.026	0.592	9.436	12.797	0.642
5.239	13.573	2.238	7.437	14.520	0.431
7.154	17.022	2.623	6.563	11.687	0.620
6.658	13.533	1.733	6.580	11.685	0.720
6.938	14.815	2.733	6.448	11.507	0.728
6.655	12.532	0.221	6.232	11.392	0.728
6.595	**13.756**	**1.757**	**5.800**	**10.922**	**0.583**
3.711	4.562	0.837	2.156	3.129	0.141
0.757	0.931	0.171	0.440	0.639	0.029
7.977	**16.274**	**1.746**	**6.562**	**12.401**	**0.606**
3.257	3.809	0.931	2.193	2.346	0.169
1.151	1.347	0.329	0.775	0.829	0.060
5.143	**12.059**	**1.795**	**5.181**	**9.978**	**0.565**
2.788	4.159	1.116	2.404	2.693	0.118
0.986	1.470	0.395	0.850	0.952	0.042
6.666	**12.935**	**1.729**	**5.658**	**10.386**	**0.577**
4.719	5.026	0.434	1.888	3.946	0.147
1.668	1.777	0.153	0.668	1.395	0.052

Yellow BF Mz max value (N.m)	Yellow BF Mz Range (N.m)	Yellow BF Mz max time (s)	Yellow BF Tz Max Value (N.m)	Yellow BF Tz Range (N.m)	Yellow BF COFxy max
9.467	12.469	1.789	6.193	10.330	0.133
1.094	6.234	1.577	11.142	18.089	0.415
8.878	13.425	2.266	6.994	8.161	0.682
8.817	14.628	3.111	5.811	10.787	0.974
5.189	12.651	1.760	4.475	7.069	0.984
6.844	12.504	2.441	6.680	13.034	0.404
5.486	11.504	2.222	7.027	12.245	0.444
5.595	10.912	1.125	3.900	8.643	0.426
8.818	18.901	1.164	5.187	14.212	0.970
2.934	9.087	1.859	8.384	11.233	0.399
1.406	7.328	1.177	4.869	7.932	0.501
4.158	19.424	3.498	3.443	18.399	0.969
6.246	17.164	2.619	7.787	10.873	0.879
10.675	14.810	1.556	9.577	19.218	0.567
10.164	21.000	1.746	3.795	7.503	0.402
7.044	10.699	1.451	2.307	6.879	0.509
10.573	17.143	2.323	7.317	10.736	0.566
1.715	15.962	1.015	2.693	14.526	0.592
.		.	.		.
9.333	25.169	2.228	10.002	21.428	0.590
6.186	14.447	1.944	6.188	12.173	0.563
5.665	14.202	1.952	6.188	12.270	0.586
5.905	14.621	1.971	5.928	11.964	0.595
7.823	16.759	1.956	5.871	12.164	0.891
6.522	**14.393**	**1.946**	**6.163**	**12.168**	**0.610**
2.891	4.364	0.612	2.262	4.000	0.231
0.590	0.891	0.125	0.462	0.816	0.047
7.727	**15.222**	**2.304**	**6.649**	**13.168**	**0.646**
2.190	2.651	0.644	1.874	4.151	0.302
0.774	0.937	0.228	0.663	1.468	0.107
5.917	**12.921**	**1.927**	**6.004**	**10.712**	**0.605**
2.939	4.437	0.510	2.752	3.716	0.242
1.039	1.569	0.180	0.973	1.314	0.086
6.074	**15.140**	**1.651**	**5.898**	**12.749**	**0.584**
3.379	5.509	0.579	2.269	4.230	0.169
1.195	1.948	0.205	0.802	1.495	0.060

APPENDIX E

(Relevant to Chapter 5)

Percieved Traction Rating Scores

	Low Handicap	SD	SE	Med Handicap	SD	SE	High Handicap	SD	SE		Total	SE
Blue	2	0.71	0.28	2	1.07	0.28	2	0.46	0.28		**2.00**	0.47
Green	1	0.64	0.2	2	0.52	0.2	2	0.53	0.2		**1.67**	0.33
Red	2	0.64	0.26	2	0.71	0.26	2	0.83	0.26		**2.00**	0.46
Black	2	0.71	0.26	3	0.71	0.26	3	0.76	0.26		**2.67**	0.45
Yellow	1	1.04	0.36	2	1.20	0.36	2	0.76	0.36		**1.67**	0.61

Percieved Ease of Natural Movement

	Low Handicap	SD	SE	Med Handicap	SD	SE	High Handicap	SD	SE		Total	SE
Blue	2	0.71	0.24	2	0.83	0.24	2	0.46	0.24		**2.00**	0.40
Green	3	0.74	0.26	2	0.76	0.26	2	0.71	0.26		**2.33**	0.45
Red	2	0.71	0.26	2	0.46	0.26	2	0.93	0.26		**2.00**	0.43
Black	1	0.52	0.21	1	0.52	0.21	2	0.71	0.21		**1.33**	0.37
Yellow	2	0.71	0.21	2	0.53	0.21	2	0.53	0.21		**2.00**	0.34

Percieved Ankle and Foot Support

	Low Handicap	SD	SE	Med Handicap	SD	SE	High Handicap	SD	SE		Total	SE
Blue	2	0.92	0.24	2	0.46	0.24	2	0.52	0.24		**2.00**	0.34
Green	3	0.74	0.22	2	0.46	0.22	2	0.64	0.22		**2.33**	0.35
Red	2	0.92	0.28	2	0.71	0.28	2	0.76	0.28		**2.00**	0.46
Black	2	0.92	0.23	3	0.46	0.23	2	0.46	0.23		**2.33**	0.32
Yellow	2	0.89	0.3	2	0.64	0.3	2	0.99	0.3		**2.00**	0.51

APPENDIX F

(Relevant to Chapter 6)

In-Shoe Planter Pressure Measurements of Different Golf Shoe Sole Designs

Informed Consent Form:

For the research you will be required to play approximately 100 golf shots using three different clubs in various types of golfing footwear (provided by the university). Shots will be played off a driving matt (either directly or off tee pegs) into golf netting. Shots will be recorded using two separate cameras and weight / foot movement patterns will be collected and analysed via force platforms set in grass. You will also be required to wear pressure insoles within the golf shoes you are provided. The research will not be assessing shot performance, only weight and movement patterns.

I (print name and date) .... hereby give my consent to participate in the testing explained to me. I am satisfied that I understand the procedures involved and accept the possible injury risks involved in the testing. I understand that I may withdraw from the experiment at anytime without reason.

Subjects full signature: ....

Experimenters signature: ....

Date:...

APPENDIX G

(Relevant to Chapter 6)

Raw Data 6.A

Front Foot In-shoe Pressures (BW)
Black Shoe 7Iron Swing Pressures

Front Foot In-shoe Pressures (BW)
Black Shoe Driver Swing Pressures

Subject	b7f1r	b7f2r	b7f3r	b7f4r	b7f5r	b7f6r	b7f7r	b7f8r	b7f9r	bdf1r	bdf2r	bdf3r	bdf4r	bdf5r	bdf6r	bdf7r	bdf8r	bdf9r
1	86.48	25.74	75.94	9.96	110.9	2.89	103.6	104.9	63.62	117.6	27.88	130.9	20.54	147.8	3.97	93.52	108.7	95.23
2	145.8	16.56	101.4	9.1	109.9	1.76	81.9	120.7	113.3	89.48	10.66	65.54	8.2	94.72	1.66	95.46	143.4	145.7
3	179.9	19.98	117	9.16	116.4	1.27	73.88	82.94	85.16	186.1	13.62	133	5.72	119.9	0.45	100.3	104	101.5
4	93.41	10.16	43.72	2.88	89.65	.	67.84	55.34	78.27	55.86	21.85	59.96	4.26	81.38	.	96.96	85.04	89
5	154.7	26.78	145.5	9.38	146.1	0.93	130.4	199.9	170.1	170.6	32.22	149.6	11.36	140.7	0.78	144.6	234.6	181.9
6	167.7	42.52	109.8	14.1	95.2	2.24	73.22	108.4	101.8	197.2	24.96	132.5	10.96	78.66	3.74	69.16	148.7	130.2
7	174.5	21.14	120.7	9.12	126.5	2.28	107.9	146.6	159.1	104.7	13.5	85.5	8.4	103.8	2.26	110.5	179.4	184.7
8	139.3	13.32	104.8	4.66	124.1	0.62	85.66	59.08	64.3	104.7	22.96	111.3	6.32	114.5	1.32	98.66	112.2	97.26
9	141.7	24.54	96.76	6.1	129.6	2.96	96.8	141.8	132.3	155.1	24.8	100.4	19.98	156.3	1.97	72.14	104.6	124.7
10	118.5	26.26	90.84	12.58	85.18	4.2	117	117.8	132.3	117.9	25.46	101.4	14.28	103.9	4.1	113.6	149	154.9
11	64.64	21.42	44.6	12.97	82.86	.	104	92.58	72.14	33.98	15.42	36.34	10.33	86.84	.	131	132.7	88.9
12	95.18	27.7	85.46	11.62	110.7	2.51	94.48	170	182.3	160.1	31.92	104.1	13.18	106.4	2.8	107.5	205.1	105.9
13	66.96	29.52	58.8	2.72	73.7	.	81.7	72	48.36	34.48	30.36	41.3	20.68	46.22	.	116.4	107.7	76.6
14	89.92	57.32	53.92	11.96	76.22	2.86	94.82	108.6	83.34	41.24	62.22	44.04	24.28	113	.	125.4	85.2	94.79
15	92.76	11.42	67.36	7.95	94.96	1.07	82.24	108.9	108.2	54.16	58.97	50.08	23.86	91.84	.	102.7	136.1	98.72
16	56.96	44.84	46.7	13.95	106	.	79	72.78	59.14	33.14	26.04	70.58	15.58	94.16	.	116.2	123.1	78.94
17	103.4	17.64	73.42	16.88	96.02	2.53	51.44	90.6	48.5	140.4	23.5	101.7	22.46	89.5	2.18	48.88	92.6	195.3
18	80.2	37.45	49.16	12.97	85.76	1.34	91.84	44.16	103.4	87.88	27.96	53.3	0.76	72.9	1.26	100.9	89.37	39.48
Mean	**114.01**	**26.35**	**82.55**	**9.89**	**103.32**	**2.10**	**89.87**	**105.39**	**100.31**	**104.71**	**27.46**	**87.31**	**13.40**	**102.36**	**2.21**	**102.44**	**130.09**	**115.76**
SD	39.65	12.41	30.26	3.95	20.09	0.99	18.79	40.59	41.19	54.93	13.62	35.96	7.22	27.32	1.23	22.75	41.79	42.09
SE	9.35	2.93	7.14	0.93	4.74	0.23	4.43	9.57	9.72	12.95	3.21	8.48	1.70	6.44	0.29	5.36	9.86	9.93

Key

b = Black Shoe　7 = 7iron　f = Pressure Result　1-9r = In-shoe Region (see figures 6.2 and 6.3)

g = Green Shoe　d = Driver　a = Average Result

y = Yellow Shoe

Front Foot In-shoe Pressures (BW)
Green Shoe 7Iron Swing Pressures

Raw Data 6.B

Front Foot In-shoe Pressures (BW)
Green Shoe Driver Swing Pressures

	g7f1r	g7f2r	g7f3r	g7f4r	g7f5r	g7f6r	g7f7r	g7f8r	g7f9r	gdf1r	gdf2r	gdf3r	gdf4r	gdf5r	gdf6r	gdf7r	gdf8r	gdf9r
	92.94	21.8	83.84	18.2	125.4	3.92	115.5	124.8	59.48	100.2	27.92	92.5	18.96	108.8	2.96	141.5	189.8	116.1
	115.8	21.5	91.16	14.95	118.5	1.4	75.72	143.8	147.8	99.04	49.96	88.74	12.42	134.8	2.84	82.14	138.2	132.4
	183.4	38.3	126.6	11.96	153.8	1.06	68.14	102.3	96.76	173.8	38.68	116	14.38	162.1	1.4	80.16	125.7	125.8
	36.14	54.6	28.06	18.6	95.28	0.43	68.18	50.76	51.6	28.54	48.02	29.68	21.22	91.8	0.5	86.84	84.56	56.02
	144.1	27.4	140.3	17.98	148.1	3.68	130.8	198.7	157.2	146.3	26.64	136.7	17.12	149.8	3	117.8	197	163
	158.7	35.84	122.3	27.9	150	3.08	105.9	119.5	115.2	160	28.28	98.5	23.32	110	2.96	84.54	114.9	123.5
	191.9	37	135	19.32	148.9	2.16	83.02	135.7	131.6	130.2	29.24	128.5	19.12	147.5	1.88	101.7	172.8	142
	152.7	36.48	144.3	18.42	108	.	70.66	47.46	56.48	85.44	33.78	95.3	19.88	96	0.7	92.14	121.8	84.46
	107.4	22.24	96.62	17.16	146	3.07	96.72	176.8	146.6	119.9	24.86	105.7	18.28	152.6	2.97	86.18	163.2	147.7
	101.1	21.72	82.18	10.34	113.1	2.86	85.18	128.1	154.7	115.2	24.7	104.3	14	125.7	2.27	88.28	150.9	159
	60.44	13.2	40.9	11.93	102.7	.	89.82	81.72	56.56	43.28	32.85	69.97	22.97	95.38	.	126.7	124.1	85.3
	129.7	28.7	101.8	23.7	117.9	2.58	102.5	176.9	156	134.2	45.96	104	24.6	117.7	3.7	95.2	198	177.3
	89.24	43.76	23.12	19.86	74.4	.	99.94	79.24	61.82	23.8	39.04	23.98	18.18	65.8	.	103.5	108.8	75.72
	130.4	55.86	30.52	21.79	67.94	.	92.1	110.1	74.94	43.1	37.96	78.96	24.9	104.1	.	104.6	88.4	56.9
	103.4	42.52	95.97	20.4	100.7	1.97	93.12	96.82	78.7	41.44	41.64	38.04	20.58	121.7	.	91.42	118.4	74.66
	43.28	26.87	34.26	21.36	91.9	.	64.9	62.98	46.6	39.2	51.94	62.96	22.92	89.9	.	95.2	121.9	81
	132	24.56	83.46	20.86	108.7	4.06	38.1	94.66	108.6	140.3	29.32	88.9	26.44	138.5	2.42	88.95	100.6	190.1
	99.42	12.64	48.76	12.94	86.78	.	125.3	67.6	56.96	65.24	41.89	44.48	9.96	64.74	.	83.2	67.94	70.94
Mean	**115.12**	**31.39**	**83.84**	**18.20**	**114.33**	**2.52**	**89.20**	**111.01**	**97.64**	**93.84**	**36.26**	**83.74**	**19.40**	**115.38**	**2.30**	**97.23**	**132.61**	**114.54**
SD	43.13	12.55	41.03	4.49	26.65	1.15	23.06	43.98	42.06	48.96	8.90	32.92	4.55	28.75	0.99	16.62	38.74	42.68
SE	10.17	2.96	9.68	1.06	6.29	0.27	5.44	10.37	9.92	11.55	2.10	7.76	1.07	6.78	0.23	3.92	9.14	10.07

Front Foot In-shoe Pressures (BW)
Yellow Shoe 7Iron Swing Pressures

Raw Data 6.C

Front Foot In-shoe Pressures (BW)
Yellow Shoe Driver Swing Pressures

	y7f1r	y7f2r	y7f3r	y7f4r	y7f5r	y7f6r	y7f7r	y7f8r	y7f9r	ydf1r	ydf2r	ydf3r	ydf4r	ydf5r	ydf6r	ydf7r	ydf8r	ydf9r
	160.8	22.03	124.6	17.55	100.9	0.88	50.93	61.3	60.48	151	20.54	107.5	12.52	106.1	3.56	106.1	165.4	119.9
	140.9	44.62	115.1	10.44	116.4	1.81	85.24	139.8	117.6	72.76	9.28	78.62	17.96	116.3	1.67	107	158	151.8
	148.2	26.14	106.6	11.12	131.4	1.8	73.54	123.5	114.7	169.3	27.52	133	13.3	113.8	1.48	66.06	120.2	119.1
	92.52	47.44	24.62	12.4	53.24	.	64.26	59.34	46.08	33.38	50.16	34.54	19.14	60.34	.	92.14	123.3	68.98
	174.3	27.3	154	16.82	127.4	3.8	135.7	198.8	147.2	174.5	29.1	141.9	18.5	109.6	3.06	135.9	214.9	158.7
	163.1	33.3	124	25.04	129.5	2.66	113.7	138.6	125.6	163.2	36.78	108	25.58	116.4	2.32	96.58	149.1	139
	155.2	21.32	124.8	10.7	117.6	2.43	95.42	158.9	136.8	114.5	16.54	99.68	10.86	86.36	2.98	91.46	156.3	133
	179.7	36.32	104	19.2	102.7	.	81.36	67.14	32.98	87.86	23.54	93.44	18.02	84.52	0.68	86.48	104	73.54
	124.4	42.56	101.3	15.66	142.1	3.46	104.2	178.3	142	120	17.96	96.74	15.28	133.7	1.97	101.5	181.5	148.8
	110.5	25.18	83.32	12.7	97.7	3.54	104.7	140.8	145.1	105.4	21.82	89.9	14.92	96.62	4.58	98.42	139.9	151.3
	72.82	11.76	38.58	13.95	70.14	.	91.18	94.36	67.78	51.68	9.1	44.97	18.89	34.82	.	99.02	124.1	95.12
	98.6	21.68	74.46	15.1	115.8	4.3	101.8	179.1	172.5	137.5	23.84	93.42	15.66	99.58	2.66	93.1	182.8	174.5
	89.53	28.02	59.56	11.34	43.2	.	92.26	94.22	62.38	38.7	36.6	56.96	20.64	40.98	.	121	126.3	84.22
	51.02	24.62	37.56	19.62	70.34	1.68	96.56	101.2	58.64	62.48	84.54	58.56	20.8	76.34	.	65.62	76.14	40.74
	25.46	52.46	39.84	24.97	74.78	.	91.84	123	95.48	32.48	113	42.38	28.67	84.04	0.5	91.48	114	92.78
	142.5	41.54	35.97	12.96	67.42	.	57.2	86.92	65.36	33.76	35.74	35.24	14.74	64.84	.	94.88	123.2	78.64
	105.9	23.9	56.22	21.04	71.3	2.68	34.34	79.6	144.1	107.8	26.3	60.6	19.1	90.6	2.5	94.5	76.5	188.1
	75.24	13.44	59.76	10.86	79.48	.	114.9	67.74	104.9	71.62	12.38	44.44	2.22	62.04	.	92.9	73.08	58.8
Mean	**117.27**	**30.20**	**81.33**	**15.64**	**95.07**	**2.64**	**88.28**	**116.26**	**102.20**	**96.00**	**33.04**	**78.88**	**17.04**	**87.61**	**2.33**	**96.34**	**133.82**	**115.39**
SD	44.24	11.62	39.03	4.73	29.61	1.05	24.95	43.81	42.04	49.32	26.55	33.10	5.73	27.18	1.17	16.21	38.92	42.85
SE	10.43	2.74	9.20	1.12	6.98	0.25	5.88	10.33	9.92	11.63	6.26	7.81	1.35	6.41	0.28	3.82	9.18	10.11

Back Foot In-shoe Pressures (BW)
Black Shoe 7Iron Swing Pressures

Raw Data 6.D

Back Foot In-shoe Pressures (BW)
Black Shoe Driver Swing Pressures (kPa)

Subject	b7f1r	b7f2r	b7f3r	b7f4r	b7f5r	b7f6r	b7f7r	b7f8r	b7f9r	bdf1r	bdf2r	bdf3r	bdf4r	bdf5r	bdf6r	bdf7r	bdf8r	bdf9r
1	20.45	42.94	8.83	51.1	19.5	53.8	77.92	57.21	89.76	23.87	34.68	7.59	41.38	15.96	67	79.08	61.22	43.92
2	34.5	54.32	13	61.26	10.22	76.72	33.6	62.21	92.14	39.8	60.48	11.9	56.96	12.38	69.12	44.96	69.39	75.84
3	30.92	75.02	7.35	40.48	6.43	50.04	46.28	42.16	75.28	38.06	84.56	6.93	40.64	14.39	48.5	53.04	55.97	76.72
4	33.16	49.74	16.3	49.04	3.82	53.06	57	51.74	76.86	30.66	53.32	15.56	57.3	6.95	69.46	54.9	53.14	80.56
5	37	71.5	8.97	54.9	3.3	73.96	41.1	50.64	89.08	42.36	85.08	11.97	53.96	5.24	77.48	64.94	70.96	114.5
6	42.97	67.39	15.68	67.88	4.1	54.53	63.28	49.4	67.28	52.26	69.38	19.68	82.3	5.48	44.04	82.74	66.87	50.88
7	33.24	58.22	8.04	56.1	14.36	84.56	48.86	44.42	103.7	29.78	55.42	8.72	59.5	14.2	89.52	62.86	50.4	105.6
8	44.02	52.52	12.97	68.62	12.54	78.32	70.74	58.82	79.87	39.56	84.64	26.3	76.86	12.64	90.14	71.12	58.96	129.5
9	51.78	78.64	19.26	58.82	4.72	71.32	67.24	55.88	48.14	44.16	66.42	14.41	54.78	5.32	67.93	64.38	71.4	51.06
10	40.82	64.82	7.76	34.38	15.64	69.38	50.7	63.03	66.88	41.28	77.54	8.26	44.12	14.46	75.92	66.04	64.8	60.74
11	49.38	72.86	7.34	42.14	3.38	24.98	50.6	73.04	76.6	53.08	79.26	11.59	46.52	4.04	26.48	50.14	70.72	71.06
12	20.42	38.26	15.38	51.98	5.08	59.54	65.7	73.56	103.6	10.22	46.08	15.5	58.92	4.92	77.68	72.42	74.22	97.02
13	50.57	78.38	7.92	42.74	2.16	24.92	76.36	49.08	73.86	42.83	97.96	9.48	51.94	2.28	72.37	89.78	71.6	65.76
14	18.94	34.64	12.12	41.26	2.08	45.74	50.74	51.08	79.52	21.85	26.52	7.9	37.6	4.97	57.26	63.22	64.68	101.5
15	30.36	61.7	16.18	75.6	3.25	73.43	44.86	74.23	126.5	37.5	62.12	12.86	75.7	7.95	79.38	83.12	68.96	132.2
16	30.2	43.78	14.34	70.28	3.5	78.92	72.7	59.98	105.9	32.78	75.35	12.97	55.95	6.39	81.49	81.78	73.76	108.7
17	17.8	49.34	6.22	71.98	3.96	74.12	57.54	50.46	75.84	16.08	81.54	9.76	71.14	4.9	79.88	77.2	76.28	87.8
18	29.94	39.46	8.14	27.3	10.12	72.42	78.96	60.32	40.04	32.6	51.88	8.5	30.34	10.08	34.38	92.32	67.95	36.82
Mean	**34.25**	**57.42**	**11.43**	**53.66**	**7.12**	**62.21**	**58.57**	**57.07**	**81.71**	**34.93**	**66.24**	**12.22**	**55.33**	**8.48**	**67.11**	**69.67**	**66.18**	**82.79**
SD	10.78	14.49	4.03	13.91	5.28	17.67	13.62	9.58	20.68	11.50	19.07	4.88	14.26	4.38	18.13	13.74	7.48	28.74
SE	2.54	3.42	0.95	3.28	1.24	4.17	3.21	2.26	4.88	2.71	4.50	1.15	3.36	1.03	4.28	3.24	1.76	6.78

Key

b = Black Shoe	7 = 7iron	f = Pressure Result	1-9r = In-shoe Region (see figures 6.2 and 6.3)
g = Green Shoe	d = Driver	a = Average Result	
y = Yellow Shoe			

Raw Data 6.E

Back Foot In-shoe Pressures (BW)
Green Shoe 7Iron Swing Pressures

	g7f1r	g7f2r	g7f3r	g7f4r	g7f5r	g7f6r	g7f7r	g7f8r	g7f9r
	30.06	47.18	17.8	36.58	14.56	49.74	77.34	62.48	87.54
	35.68	44.16	12.84	46.1	13.72	70.7	38.7	54.2	77.86
	38.42	77.24	12.87	36.6	1.27	48.6	53.2	43.86	67.74
	33.04	40.56	21.52	45.56	6.88	57.56	45.18	52.72	56.76
	56.68	78.08	10.56	44.76	5.66	74.42	41.66	70.1	91.5
	51.87	78.98	31.89	84.54	3.94	56.6	81.04	57.08	50.58
	52.58	61.88	14.38	54.88	9.84	65.34	42.52	52.12	88.28
	42.06	41.3	35.02	45.64	15.08	83.46	61.66	75.96	131.2
	36.12	44.2	16.94	37.64	3.66	64.13	68.5	61.72	51.64
	44.82	62.76	13.1	35.86	14.3	61.5	52.72	76.78	71.46
	42.04	55.56	12.54	34.66	2.88	44.24	74.78	86.34	79.56
	34.66	43.76	15.54	44.2	4.7	61.4	64.52	73.28	73.84
	64.76	88.92	13.22	46.78	3.63	55.34	69.66	67.08	64.26
	22.78	43.53	14.76	44.87	7.16	44.74	60.3	84.44	76.5
	38.96	61.76	12.04	66.54	3.52	85.32	45.76	79.86	136.5
	50.9	57.6	21.18	64.46	2.4	78.38	66.88	74.24	119.5
	24.98	73.94	12.26	72.24	8.4	69.34	56.7	55.3	62.94
	28	38.82	13	29.3	7.62	58.43	79.42	63.95	62.87
Mean	**40.47**	**57.79**	**16.75**	**48.40**	**7.18**	**62.74**	**60.03**	**66.20**	**80.59**
SD	11.42	15.98	6.80	14.70	4.56	12.40	13.73	12.19	25.38
SE	2.69	3.77	1.60	3.47	1.07	2.92	3.24	2.88	5.98

Back Foot In-shoe Pressures (BW)
Green Shoe Driver Swing Pressures

	gdf1r	gdf2r	gdf3r	gdf4r	gdf5r	gdf6r	gdf7r	gdf8r	gdf9r
	27.44	45.64	11.1	33.56	12.94	61.78	79.92	46.4	32.12
	50	60.64	14.92	54.02	9.66	61.36	40.92	42.87	62.34
	46.12	80.64	18.4	50.04	2.24	80.56	66.32	54.64	65.2
	20.08	58.75	14.32	34.42	9.9	73.9	48.1	66.72	79.92
	56.08	75.28	10.9	46.32	7.02	91.6	46.02	56.6	86.28
	77.16	78.45	26.83	76.04	2.5	46.96	87.38	61.52	46.86
	56.18	66.52	18.14	54.44	13.18	87.54	45.24	57.66	89.84
	41.12	45.12	25.63	57.66	10.61	82.22	57.54	69.26	133.2
	40.3	49.76	19.02	44.78	4.18	41.98	84.52	62.44	46.52
	51.94	74.02	13.7	42.94	14.3	67.16	72.04	80.06	79.32
	51.82	68.26	14.86	54.84	2.58	34.94	56.16	67.06	66.94
	26.56	38.06	12.34	47.12	6.46	64.89	73.18	95.76	94.04
	32.85	68.93	14.5	58	7.09	69.97	89.8	95.9	67.9
	19.16	78.46	12.78	42.89	7.18	65.2	60.12	79.76	84.74
	43.94	85.6	18.8	79.4	6.2	73.89	51.5	94	140
	33.85	83.76	20.92	73.16	5.12	68.85	65.16	91.65	103.1
	16.02	64.26	16.75	54.56	9.38	81.26	76.2	90.82	95.36
	24.64	66.93	12.74	25.24	8.94	67.98	78.37	56.72	43.44
Mean	**39.74**	**66.06**	**16.48**	**51.64**	**7.75**	**67.89**	**65.47**	**70.55**	**78.73**
SD	16.10	14.08	4.57	14.37	3.67	15.07	15.52	17.47	28.93
SE	3.80	3.32	1.08	3.39	0.87	3.55	3.66	4.12	6.82

Back Foot In-shoe Pressures (BW)
Yellow Shoe 7Iron Swing Pressures

Raw Data 6.F

	yy7f1r	y7f2r	y7f3r	y7f4r	y7f5r	y7f6r	y7f7r	y7f8r	y7f9r
	20.76	32.65	14.9	36.42	31.03	50.63	89.8	77.83	64.86
	43.02	54.8	15.34	54.98	13.58	86.36	38.24	59.53	76.04
	33.36	61.16	11.01	38.34	0.23	53.06	49.16	53.48	79.14
	20.18	27.64	14.66	29	5.9	39.92	48.66	63.08	59.02
	47.16	69.4	10.62	46.82	6	68.42	41.42	71.8	95.34
	57.86	64.86	16.56	80.08	0.3	49.24	81.36	60.82	43.98
	34.3	54.88	12.18	48.44	5.76	71.88	50.34	76.42	90.38
	20.72	72.78	12.97	50.46	12.94	75.28	74.66	86.24	122
	37.76	61.28	19.18	45.4	4.98	52.52	77.76	74.62	57.76
	31.99	64.84	12.38	37.54	22.36	78.9	72.46	85.23	83.02
	38.14	58.04	13.96	35.46	0.5	38.41	61.32	96.58	72.54
	25.74	41.14	11.84	41.06	2.64	43.46	56.9	75.78	75.6
	48.97	82.18	12.87	38.76	0.43	26.98	63.32	70.08	52.76
	21.78	38.28	12.64	38.82	2.68	31.54	48.04	73.04	79.16
	20.43	63.87	10.76	63.87	.	75.78	56.38	93.7	145.2
	41.92	68.96	18.46	76.56	1.78	65.31	58.2	93.52	112.8
	23.89	72.02	10.76	61.92	4.98	61.46	65.52	89.52	82.86
	39.56	41.66	19.9	36.42	2.8	41.28	79.28	60.24	47.74
Mean	**33.75**	**57.25**	**13.94**	**47.80**	**6.99**	**56.14**	**61.82**	**75.64**	**80.01**
SD	11.43	15.17	2.94	14.47	8.52	17.51	14.78	13.07	26.33
SE	2.70	3.58	0.69	3.41	2.01	4.13	3.49	3.08	6.21

Back Foot In-shoe Pressures (BW)
Yellow Shoe Driver Swing Pressures

	ydf1r	ydf2r	ydf3r	ydf4r	ydf5r	ydf6r	ydf7r	ydf8r	ydf9r
	27.3	47.76	13.82	52.96	15.27	57.32	77.38	86.29	47.93
	47.34	66.1	12.7	54.12	12.56	79.12	49.24	54.2	61.52
	34.6	57.2	8.37	33.44	8.57	51.46	49.3	68.32	69.74
	16.98	75.96	14.22	33.62	6	55.74	53.76	77.78	80.58
	49.4	75.32	10.6	52.5	5.66	74.7	62.62	78.22	94.62
	61.74	63.86	18.87	77.08	5.49	43.76	80.08	57.06	43.06
	34.5	51.98	10.44	41.4	6.46	62.74	47.4	65.32	68.8
	30.66	85.93	20.62	58.12	6.76	68.08	48.96	61.08	120.3
	35.26	51.1	17.14	38.32	6.44	11.82	70.82	58.44	43.42
	50.66	68.08	15.38	40.1	9.65	72.8	71.98	95.44	75.96
	38.56	58.9	13.16	35.58	5.43	46.97	48.68	76.98	59.66
	23.64	45.18	13.1	52.44	3.46	56.82	76.58	101.3	100.1
	66.4	91.92	9.84	43.5	2.06	34.8	88.54	85.96	63.08
	16.92	43.08	12.12	51.24	2.18	47.52	57.26	86.48	98.24
	32.96	81.78	11.62	47.78	3.87	72.54	74.78	95.34	125
	58.98	77.63	22.5	87.44	2.58	73.97	95.18	96.86	123.5
	26.75	71.18	8.29	63.48	4.52	72.97	74.12	92.64	89.6
	43.2	87.4	18.5	31.5	2.6	31.85	79.38	57.9	28.5
Mean	**38.66**	**66.69**	**13.96**	**49.70**	**6.09**	**56.39**	**67.00**	**77.53**	**77.42**
SD	14.66	15.27	4.13	15.09	3.57	18.07	15.14	15.81	28.84
SE	3.46	3.60	0.97	3.56	0.84	4.26	3.57	3.73	6.80

Ball Impact In-Shoe Pressure Front Foot Results (BW)

Raw Data 6.G

	Black Shoe 7Iron Front Foot									Black Shoe Driver Front Foot								
Subject	**b71**	**b72**	**b73**	**b74**	**b75**	**b76**	**b77**	**b78**	**b79**	**bd1**	**bd2**	**bd3**	**bd4**	**bd5**	**bd6**	**bd7**	**bd8**	**bd9**
1	40.44	15.93	45.3	9.83	29.54	14.92	29.76	40.64	32.42	53.43	7.52	23.52	6.16	39.18	3.14	21.98	48.56	74.66
2	31.28	4.38	44.9	2.44	74.48	0.66	39.18	63.68	45.54	43.92	2.1	29.8	2.04	37.78	0.48	32.64	39.84	44.6
3	31.44	11.62	13.4	3.44	14.22	0.34	14.84	41.1	61.88	47.84	5.46	22.18	2.72	20.56	0	19.4	42.74	57.16
4	22.42	14.47	25.24	3.94	27.92	0.43	29.3	27.46	25.48	18.5	1.28	22.36	1	21.26	0	28.36	33.16	21.62
5	12.66	2.48	10.48	2.6	26.39	0.18	30.46	65.04	54.76	21.98	3.58	19.14	2.62	22.34	0.04	35.42	87.66	43.78
6	65.58	4.64	38.44	6.32	18.58	0.84	16.78	35.38	43	35.74	4.61	42.25	3.95	16.43	1.55	23.88	30.25	42.93
7	40.56	9.45	28.32	2.86	37.92	1.56	22.22	55.18	46.81	60.78	1.86	37.44	3.78	37.7	0.84	25.18	43.34	45.64
8	34.52	4.76	25.65	3.98	38.82	0.36	23.96	15.42	28.52	40.64	2.28	53.92	0.32	26.44	0.2	41.82	23.4	30.76
9	44.92	4.66	28.32	1.85	27.94	0.36	12.94	12.16	10.48	53.67	4.88	44.98	0.46	31.38	0.8	22.54	52.56	28.77
10	75.22	13.3	45.42	1.84	58.54	1.74	34.42	50.2	82.9	64.48	6.78	31.16	1.46	38.28	2.45	36.26	52.92	78.82
11	24.34	4.86	23.32	1.3	33.52	1.5	64.46	45.21	83.6	15.58	3.3	10.98	0.7	25.92	0.9	72.68	51.76	54.7
12	11.85	8.63	13.65	2.84	31.54	0	22.3	36.17	31.51	11.82	4.98	26.25	3.58	21.24	0	28.44	40.8	45.16
13	27.57	18.68	28.38	7.62	27.32	1.66	36.76	62.44	25.15	24.22	9.72	31.38	5.5	35.48	1.04	51.34	93.12	64.78
14	11.02	10.36	9.9	2.56	16.28	0	23.72	22.06	27.16	32.85	4.26	17.36	3.64	27.23	0	28.92	34.84	38.58
15	22.82	5.44	10.14	4.28	39.38	0	64.38	37.21	42.62	42.61	3.7	28.83	1.2	13.68	1.48	42.84	27.72	46.79
16	23.87	9.49	31.35	2.74	18.17	0.39	48.17	46.6	35.97	31.74	2.32	19.25	0.92	37.56	0	43.3	30.84	30.94
17	10.18	7.24	10.34	4.7	26.24	0	28.22	34.36	34.04	15.42	8.86	8.5	6.08	27.23	0	25.38	27.8	32.06
18	25.62	5.92	9.14	4.4	19.75	0.68	15.76	24.64	39.58	30.22	3.88	12.67	3.28	19.43	0.48	14.52	35.28	90.02
Mean	**30.91**	**8.68**	**24.54**	**3.86**	**31.48**	**1.42**	**30.98**	**39.72**	**41.75**	**35.86**	**4.52**	**26.78**	**2.75**	**27.73**	**0.74**	**33.05**	**44.26**	**48.43**
SD	17.74	4.60	12.99	2.18	15.05	3.42	15.20	15.84	19.18	16.16	2.40	12.16	1.89	8.32	0.91	13.78	19.06	18.63
SE	4.18	1.08	3.06	0.51	3.55	0.81	3.59	3.74	4.52	3.81	0.57	2.87	0.45	1.96	0.22	3.25	4.49	4.39

Key

b = Black Shoe
g = Green Shoe
y = Yellow Shoe

7 = 7iron
d = Driver

f = Pressure Result
a = Average Result

1-9r = In-shoe Region (see figures 6.2 and 6.3)

Ball Impact In-Shoe Pressure Front Foot Results (BW)

Green Shoe 7Iron Front Foot | **Raw Data 6.H** | **Green Shoe Driver Front Foot**

	g71	g72	g73	g74	g75	g76	g77	g78	g79	gd1	gd2	gd3	gd4	gd5	gd6	gd7	gd8	gd9
	30.18	5.76	37.38	5.06	82.66	1.18	46.21	62.18	32.74	43.76	11.82	43.98	9.23	31.26	1.62	31.28	75.78	71.42
	34.72	6.9	41.78	1.56	67.74	0	28.88	39.84	22.62	50.46	10.58	44	5.3	28.54	0.78	38.62	68.58	54.32
	29.67	14.44	33.37	3.76	66.74	1.95	30.88	47.82	56.28	53.26	14.46	29.68	4.44	31.24	0.18	22.3	54.84	72.32
	6.74	8.48	9.48	4.68	24.86	1.56	25.82	31.36	30.28	33.62	5.5	7.22	2.48	21.42	0	23.56	22.48	24.76
	45.92	21.1	44.14	5.47	84.83	0.43	71.3	25.5	44.52	64.42	16.9	46.43	6.8	51.43	1.43	63.38	27.86	39.67
	30.47	18	32.38	3.98	45.64	1.78	26.8	47.56	62.58	78.38	12.74	19.42	12.9	12.76	0.88	35.46	47.94	71.44
	50.24	9.68	38.96	4.9	44.06	0.76	16.32	46.12	42.42	43.68	9.76	41.12	6.1	50.24	0.18	25.36	48.58	23.72
	15.5	5.22	22.06	2.74	25.04	1.87	27.3	28.68	30.14	24.5	9.3	31.98	5.28	32.94	0.1	38.28	38.1	29.16
	42.14	5.92	29.14	1.58	43.7	1.64	18.5	21.68	12.26	15.5	7.14	14.48	0.48	35.82	0	31.84	46.06	48.42
	58.82	11.56	35.86	6.04	35.84	1.4	34.48	48.86	66.18	53.58	12.06	33.54	10.32	33.1	3.18	26.88	67.96	85.46
	22.84	3.7	13.86	1.28	24.04	2.28	31.3	54.06	51.3	31.8	6.18	29.68	4.34	42.68	1.22	57.78	75.67	74.65
	25.92	2.22	9.56	3.93	19.3	1.36	39.98	54.28	53.84	11.68	2.32	49.23	1.04	10.38	0	46.12	53.6	49.62
	37.46	12.94	24.72	11.1	23.36	2.02	31.12	75.78	78.28	55.9	13.98	42.53	13.8	29.4	1.55	43.1	69.47	40.68
	20.38	7.62	10.48	4.16	33.72	1.79	21.6	29.5	34.76	21.52	7.88	8.24	2.8	18.56	0	26.68	31.28	35.98
	19.28	5.7	19.38	1.16	31.27	1.23	21.68	27.62	19.44	23.52	10.58	6.38	4.55	35.65	0	38.45	55.65	32.63
	29.53	6.66	41.65	2.14	35.48	2.91	52.98	57.1	37.14	25.74	3.02	32.78	3.45	24.82	1.35	43.64	32.82	45.67
	32.49	8.02	7.8	4.92	31.54	0.99	31.24	40.34	36.4	14.92	12.26	10.22	9.52	17.45	0	20.38	36	31.74
	40.42	8.34	24.2	5.8	18.74	1.1	19.43	32.88	51.98	50.02	10.34	27.2	4.92	17.92	1.38	23.3	28.72	56.1
Mean	**31.82**	**9.01**	**26.46**	**4.13**	**41.03**	**1.46**	**31.99**	**42.84**	**42.40**	**38.68**	**9.82**	**28.78**	**5.99**	**29.20**	**0.77**	**35.36**	**48.97**	**49.32**
SD	12.84	4.92	12.48	2.37	20.93	0.68	13.63	14.59	17.32	18.92	3.91	14.58	3.79	11.69	0.88	12.17	17.36	19.00
SE	3.03	1.16	2.94	0.56	4.94	0.16	3.21	3.44	4.08	4.46	0.92	3.44	0.89	2.76	0.21	2.87	4.09	4.48

Ball Impact In-Shoe Pressure Front Foot Results (BW)

Yellow Shoe 7Iron Front Foot — **Raw Data 6.I** — **Yellow Shoe Driver Front Foot**

	y71	y72	y73	y74	y75	y76	y77	y78	y79	yd1	yd2	yd3	yd4	yd5	yd6	yd7	yd8	yd9
	41.27	8.43	45.63	6	26.63	0.28	17.23	24.15	31.14	53.62	9.02	60.46	11.04	24.16	1.95	34.65	43.84	58.96
	30.24	3.34	31.82	3.1	31.43	1.29	21.28	56.6	50.86	49.38	8.24	46.36	3.72	52.96	1.46	30.36	62.94	48.6
	31.94	7.58	19.66	4.18	19.26	0.28	21.18	56.2	45.63	36.9	11.72	16.7	2.94	24.34	0.68	11.98	38.28	52.04
	44.69	8.38	8.42	5.12	23.24	0	14.16	32.5	28.5	26.33	5.53	47.25	2.05	18.67	0	22.48	34.7	32.33
	28.64	13.2	27.56	2.32	39.7	1.94	61.68	35.13	41.73	35.82	5.92	19.34	3.54	21.2	1.66	31.76	52.5	90.7
	45.87	16.78	48.46	7.82	38.12	1.32	31.56	51.22	49.74	64.42	15.62	49.56	14.86	28.06	0.82	24.08	49.56	63.46
	44.6	5.8	22.54	6.1	27.5	4.92	13.62	38.42	35.92	34.18	3.98	42.16	4.88	52.56	1.45	28.1	41.62	24.52
	10.04	5.12	14.46	1.04	6.6	0.64	20.3	31.98	24.16	13.38	6.36	13.28	1.56	34.56	0	21.3	29.58	26.44
	43.24	5.34	32.5	2.58	34.34	1.35	18.48	21.78	6.76	47.92	7.94	32.34	1.26	23.64	0	36.43	29.72	48.68
	28.57	3.97	14.07	3.9	8.77	5.9	28.5	53.13	69.43	47.84	6.24	31.66	4.5	48.58	1.54	49.48	87.06	75.02
	16.52	9.91	13.54	2.08	23.8	0.5	56.16	73.46	68.36	42.87	4.96	8.5	5.58	12.26	1.54	35.36	52.87	74.79
	10.1	13.23	29.74	2.5	8.83	0	32.84	54.42	52.34	24.22	3.18	8.38	0.4	24.74	0	34.2	36.66	36.98
	51.92	15.88	33.51	9.88	6.42	2.94	26.12	54.94	41.74	45.15	7.98	9.95	4.8	16.65	2.28	28.93	50.63	56.98
	42.04	12.45	22.77	2.8	8.58	0	36.38	52.48	46.44	23.63	5.3	37.75	2.16	9.88	0	46.24	49.88	35.88
	16.79	8.18	26.52	2.28	22.68	0.54	51.76	32.57	48.78	11.38	12.35	5.58	3.28	27.43	0	44.4	33.68	13.84
	19.02	3.65	36.65	1.93	10.48	0.24	63.63	34.13	60.43	35.63	3.46	41.75	2.72	19.1	0	68.42	73.36	48.28
	31.76	7.86	31.56	4.26	14.7	2.64	27.8	51.52	49.48	37.17	15.22	8.78	5.76	47.33	0	22.26	44.34	40.72
	26.14	12.39	16.62	2.78	6.62	0.8	26.46	30.14	19.1	36.6	6	18.9	2.6	21.54	1.36	28.08	49.52	57.08
Mean	**31.30**	**8.97**	**26.45**	**3.93**	**19.87**	**1.42**	**31.62**	**43.60**	**42.81**	**37.02**	**7.72**	**27.71**	**4.31**	**28.20**	**0.82**	**33.25**	**47.82**	**49.18**
SD	13.00	4.18	11.04	2.29	11.45	1.70	16.08	14.06	16.41	13.72	3.75	17.50	3.53	13.47	0.83	12.86	14.95	19.61
SE	3.07	0.99	2.60	0.54	2.70	0.40	3.79	3.32	3.87	3.24	0.89	4.13	0.83	3.18	0.20	3.03	3.53	4.62

Ball Impact In-Shoe Pressure Back Foot Results (BW)

Black Shoe 7Iron | **Raw Data 6.J** | **Black Shoe Driver**

Subject	b71	b72	b73	b74	b75	b76	b77	b78	b79	bd1	bd2	bd3	bd4	bd5	bd6	bd7	bd8	bd9
1	7.23	22.53	1.27	23.27	1.76	49.2	19.45	32.76	26.17	12.73	20.56	0.72	20.86	4.8	24.22	10.58	18.47	38.76
2	10.28	13.5	4.68	15.93	2.73	15.55	13.18	24.79	13.55	18.62	29.46	5.86	36.7	3.84	27.97	21.46	17.1	53.5
3	13.48	28.4	1.2	20.63	0	35.18	14.85	21.08	65.3	6.08	25.96	0.38	12.28	0	25.9	27.86	35.32	61.54
4	18.56	5.05	2.58	21.53	0.58	22.74	34.98	35.38	31.78	8.8	14.68	3.98	19.35	0.13	21.9	31.15	32.3	55.1
5	14.08	36.03	2.32	20.53	1.93	23.15	11.4	10.43	31.03	19.84	48.06	0.98	25.76	1.48	23.2	7.42	10.94	34.86
6	22.3	41.76	5.13	19.69	0.25	23.5	21.43	15.93	31.48	35.45	29.76	4.98	31.95	0	41.4	12.74	22.86	45.63
7	16.85	25.93	4.75	29.58	4.4	46.3	36.88	22.83	49.35	12.92	29.1	3.24	37.48	1.48	36.95	21.7	17.16	48.46
8	21.38	16.59	4.75	18.53	3.03	30.55	31	19.63	37.73	9.2	18.86	3.98	20.75	4.55	24.25	29.98	20.25	44.65
9	27.5	42.3	7.4	24.55	3.25	2.03	22.25	15.08	20.25	20.74	41.84	5.54	23.46	2.96	22.65	9.62	35.85	21.86
10	19.54	45.88	3	16.08	2.92	26.55	45.15	39.25	39.95	23.98	39.72	2.94	15.36	1.96	30.84	61.72	31.95	47.58
11	16.5	26.38	4.2	16.83	2.53	7.95	26.15	37.1	53.13	23.02	32.72	3.96	18.82	1.96	21.86	27.1	37.98	41.54
12	7.6	14.77	5.87	28.1	1.13	28.73	25.23	27.1	35.84	11.84	32.96	0.46	22.97	0.2	23.38	30.14	29.48	53.96
13	17.35	23.98	3	19.28	1.15	13.73	24.4	22.83	48.28	13.1	22.38	1.88	16.38	1.86	16.14	31.54	36.64	44.27
14	6.1	19.08	6.23	23.85	0.65	13.48	20.78	18.83	34.33	14.85	24.96	4.4	20.92	0.98	29.24	31.84	34.76	57.62
15	17.54	10.23	3.58	18.73	0.13	27.23	25.38	41.75	34.1	10.26	17.92	4.96	27.21	0	21.88	46.82	43.78	39.54
16	11.76	0	0	0	2.81	21.93	62.1	40.42	39.29	15.78	29.26	3.66	32.96	0	33.8	32.97	45.86	35.97
17	8.57	66.3	1.8	23.56	0.5	27.7	31.47	20.57	35.1	9.74	19.88	1.79	23.38	0.58	20.66	25.96	34.22	45.24
18	18.43	35	6.63	22.33	2.81	12.03	44.13	19.6	22.5	12.7	16.9	3.46	27.73	5.24	17.9	29.58	30.48	19.52
Mean	**15.28**	**26.32**	**3.80**	**20.17**	**1.81**	**23.75**	**28.35**	**25.85**	**36.06**	**15.54**	**27.50**	**3.18**	**24.13**	**1.78**	**25.79**	**27.23**	**29.74**	**43.87**
SD	5.86	16.30	2.06	6.28	1.30	12.20	12.75	9.58	12.39	7.11	9.18	1.76	7.13	1.79	6.55	13.15	9.80	11.20
SE	1.38	3.84	0.49	1.48	0.31	2.88	3.01	2.26	2.92	1.68	2.17	0.42	1.68	0.42	1.54	3.10	2.31	2.64

Key

b = Black Shoe
g = Green Shoe
y = Yellow Shoe

7 = 7iron
d = Driver

f = Pressure Result
a = Average Result

1-9r = In-shoe Region (see figures 6.2 and 6.3)

Ball Impact In-Shoe Pressure Back Foot Results (BW)

Green Shoe, 7Iron **Raw Data 6.K** **Green Shoe Driver**

	g71	g72	g73	g74	g75	g76	g77	g78	g79	gd1	gd2	gd3	gd4	gd5	gd6	gd7	gd8	gd9
	4.76	23.68	2.16	12.38	3.84	18.52	42.48	21.78	42.97	8.9	16.96	2.46	19.58	1.54	31.89	10.98	31.97	23.72
	6.78	9.48	2.58	22.81	4.97	22.13	19.58	22.78	29	21.92	24.42	5.3	13.43	1.94	36.86	29.2	24.06	32.26
	14.98	26.34	3.78	13.98	0	24.68	19.2	24.88	48.18	12.8	17.44	2.34	17.39	2.96	33.42	18.2	40.64	44.24
	9.55	11.88	5.65	22.15	0.5	19.54	22.55	20.43	26.85	6.23	28.86	3.13	16.38	0.88	31.55	25.05	31.25	50.63
	10.47	27.23	0	14.54	0.5	28.53	27.7	29.9	20.1	12.84	16.26	0.3	22.95	0.82	16.95	9.44	41.05	41.97
	27.54	58.86	3.45	27.73	1.27	39.76	23.83	31.68	38.46	28.34	19.08	4.87	19.58	0.18	24.52	28.57	24.87	26.04
	15.8	19.18	6.24	22.36	3.67	45.28	38.94	43.46	47.46	12.76	12.42	3.82	12.6	4.22	24.42	31.52	19.16	43.97
	28.28	28.54	7.43	32.4	4.32	29.23	36.08	41.9	41.75	10.18	31.68	4.85	21.15	3	36.8	42.2	37.45	53.86
	19.52	35.38	8.58	22.68	0.82	26.82	21.73	35.04	25.56	22.46	27.54	7.34	17.92	0.94	18.86	30.64	23.8	45.8
	27.7	33.24	4.3	13.48	3.91	18.42	36.37	38.57	34.92	28.6	26.89	6.52	14.1	2.85	20.54	27.85	34.98	40.2
	15.56	20.16	6.62	22.63	0.62	10.22	37.34	42.96	51.52	16.02	20.74	5.54	24.85	1.97	24.86	46.7	42.97	33.36
	10.5	15.36	3.68	18.1	0.34	11.92	41.88	44.02	28.46	17.84	12.97	1.36	12.52	0.14	11.02	36.22	37.12	32
	17.45	34.84	5.62	26.74	0	24.82	24	33.98	50.88	22.85	17.97	4.45	15.92	0	23.68	34.83	41.3	42.08
	1.96	31.65	1.04	24.57	0.28	19.44	22.58	31.72	48.7	23.86	21.95	3.78	12.7	0.62	39.74	16.84	31.14	67.98
	19.12	28.54	4.72	27.24	0	34.9	25.46	43.9	61.92	11.05	24.87	2.68	22.13	2.96	29.66	22.93	19.97	45.85
	10.56	28.81	0	26.29	0	21.83	59.08	43.94	36.94	6.9	28.32	1.4	18.58	1.74	19.92	24.97	29.48	58.46
	21.56	32.14	7.72	20.25	2.74	27.1	26.58	31.42	25.18	11.94	26	2.18	26.3	1.3	37.98	33.3	45.78	53.38
	26.01	13.19	8.76	20.35	7.39	13.57	38.22	22.09	24.71	12.92	17.58	5.28	28.95	4.14	10.54	27.97	27.72	32.97
Mean	**16.01**	**26.58**	**4.57**	**21.70**	**1.95**	**24.26**	**31.31**	**33.58**	**37.98**	**16.02**	**21.78**	**3.76**	**18.72**	**1.79**	**26.29**	**27.63**	**32.48**	**42.71**
SD	8.11	11.43	2.74	5.54	2.22	9.20	10.59	8.63	11.86	7.04	5.75	1.91	4.93	1.32	8.99	9.73	8.15	11.54
SE	1.91	2.70	0.65	1.31	0.52	2.17	2.50	2.04	2.80	1.66	1.36	0.45	1.16	0.31	2.12	2.30	1.92	2.72

Ball Impact In-Shoe Pressure Back Foot Results (BW)

Yellow Shoe 7Iron **Raw Data 6.L** **Yellow Shoe Driver**

	y71	y72	y73	y74	y75	y76	y77	y78	y79	yd1	yd2	yd3	yd4	yd5	yd6	yd7	yd8	yd9
	1.07	11.87	2.49	18.35	0.7	25.92	42.13	41.05	31.74	10.42	17.98	2.4	20.74	1.94	42.16	21.86	41.96	16.88
	15.2	17.84	4.78	23.76	3.52	45.48	29.94	27.46	34	15.43	21.1	3.9	24.08	8.07	47.4	26.05	23.35	34.8
	13.7	25.48	2.64	15.42	1.63	25.24	28.92	34.5	57.6	6.45	27.76	1.87	10.67	0	25.2	24.43	31.15	49.27
	3.8	7	3.05	13.05	0.45	17	26.45	39.3	33.35	8	12.58	5.72	19.06	2.2	34.34	26.98	43.64	64.96
	24.44	43.98	3.64	26.1	1.44	25.42	12.22	13.46	29.92	20.78	38.84	2.94	23.46	2.94	28.46	16.56	26.95	33.62
	61.34	37.5	5.5	25.92	2.39	38.9	10.43	23.04	35.76	31.85	31.85	2.86	62.76	0	37.02	12.97	39.58	31.44
	14.76	21.22	9.4	23.88	3.53	31.57	47.78	50.84	36.83	17.5	20.92	4.73	18.22	2.46	36.92	32.08	28.86	27.48
	4.4	16.65	2.66	29.47	2.54	22.42	45.58	31.2	45.04	6.1	8.75	4.72	17.6	3.43	37.7	39.28	34	61.8
	18.65	55.28	4.39	33.76	2.84	18.2	11.14	15.76	31.2	22.84	31.62	9.9	19.96	3.82	2.14	12.32	41.96	23.54
	34.8	45.23	4.03	22.63	3.91	31.63	42.52	62.63	41.77	33.08	40.94	5.14	17.7	7.98	35.62	46.56	37.97	37.86
	15.1	21.1	8.96	11.12	1.52	13.74	32.58	51.3	27.94	27.12	36	4.96	17.04	0.1	8.9	11.92	24.52	38.92
	11.8	24.28	6.08	19.94	2.65	8.16	32.64	40.88	30.38	8.54	16.4	5.12	16.78	0.48	11.96	34.48	43	46.14
	17.38	16.78	1.14	17.02	0	18.94	15.38	24.22	40.74	12.4	21.7	1.3	15.45	0	24.98	11.85	30.43	53.88
	3.98	13.58	2.48	14.1	0.32	21.94	27.1	29.64	22.36	12.95	11.12	1.84	14.96	0.1	8.7	33.34	43.14	46.04
	0.4	17.21	2.74	7.76	3.24	24.96	28.62	45.92	31.75	6.76	22.2	1.96	34.7	0	28.62	39.68	42.97	47.93
	7.55	12.03	1.85	14.78	2.52	23.79	39.08	70.1	36.94	8.34	14.36	2.28	15.18	0.38	25.52	38.38	23.97	66.64
	4.06	38.78	2.2	27.86	0.98	19.74	35.4	35.56	35.52	10.76	23.54	0.36	21.88	0.26	27.42	28.56	39.7	45.64
	37.04	39.9	3.76	36.04	0.5	19.16	51.84	37.76	23.86	18.34	20.26	9.14	19.62	0.36	10.5	64.04	37.14	13.16
Mean	**16.08**	**25.87**	**3.99**	**21.16**	**1.93**	**24.01**	**31.10**	**37.48**	**34.82**	**15.43**	**23.22**	**3.95**	**21.66**	**1.92**	**26.31**	**28.96**	**35.24**	**41.11**
SD	15.47	13.96	2.28	7.87	1.25	8.81	12.69	14.97	8.11	8.65	9.49	2.55	11.42	2.58	13.00	13.85	7.39	15.46
SE	3.65	3.29	0.54	1.86	0.29	2.08	2.99	3.53	1.91	2.04	2.24	0.60	2.69	0.61	3.07	3.27	1.74	3.65

Black Shoe 7Iron Average | **Raw Data 6.M** | **Black Shoe Driver Average**

b7a1r	b7a2r	b7a3r	b7a4r	b7a5r	b7a6r	b7a7r	b7a8r	b7a9r	bda1r	bda2r	bda3r	bda4r	bda5r	bda6r	bda7r	bda8r	bda9r
29.88	16.94	26	8.97	55.32	5.74	39.12	49.5	34.84	68.14	17.94	75.82	13.12	83.34	1.97	39.52	47.48	52.7
63.28	11.72	50.16	6.36	52.76	0.46	38.76	44.16	56.46	39.44	7.38	30.96	3.78	43.9	0.66	44.56	56.84	64.22
71.96	7.18	50.96	8.38	52.06	0.3	31.58	36.18	47.54	77.44	9.87	53.94	3.3	50.34	2.09	39.58	44.12	52.4
29.74	11.06	19.94	4.99	24.78 .		24.36	31.97	22.28	26.84	7	23.08	0.96	20.44 .		23.66	19.62	20.18
66.46	14.54	64.32	7.68	41.85	0.08	61.34	41.86	78.1	81.54	15.22	69.98	10.62	65.98	0.18	60.92	76.66	73.48
106.1	8.86	68.14	8.03	44.46	1.16	39.18	40.64	45.06	79.54	12.32	70.67	8.64	36.64	1.3	40.38	52.46	57.94
56.6	10.2	42.6	6.8	49.26	0.84	37.6	52.8	52.89	43.84	8.64	31	5.42	39.86	0.86	43.94	70.5	67.97
72.67	12.08	76.28	4.29	51.12	0.14	30.22	24.22	31.62	47.54	9.18	56.5	0.58	66.12	0.36	45.64	34.48	29.54
68.82	10.5	45.34	2.28	48.99	3.26	37.44	53.88	68.3	78.68	9.18	50.7	1.5	79.14	2.05	31.46	40.8	55.66
57.04	14.98	41.14	8.95	38.44	2.14	57.72	67.92	80.12	44.52	11.18	34.52	13.26	40.64	1.97	50.04	57.97	54.87
33.58	12.84	23.86	4.93	30.95 .		35.18	23.38	37.86	88.45	6.32	23.97	7.13	23.44 .		33.46	24.54	31.26
49.16	17.46	34.16	8.76	53.06	1.16	42.54	57.06	79.08	89.22	19.02	43.76	8.18	45.46	0.94	45.28	65.58	79.14
25.32	8.24	22.78	4.92	31.96 .		24.7	27.96	23.82	13.34	11.98	17.18	11.98	22.14 .		39.14	22.52	54.89
24.78	18.36	16.9	3.95	36.09 .		33.52	34.52	24.1	24.86	27.26	21.97	12.8	28.76 .		33.32	26.38	17.44
33	11.47	28.52	3.59	39.07 .		34.42	33.34	37.68	18.26	23.84	20.76	16.96	32.84 .		25.3	24.96	28.78
29.24	22.4	18.84	3.07	23.3 .		30.44	26.96	29.94	19.42	14.24	16.95	9.78	21.84 .		34.78	27.26	42.7
43.88	9.78	28.4	8.76	21.12	0.96	23.96	27.34	75.48	56.76	11.56	41.84	11.78	25.48	0.96	13.98	26.32	58.97
42.4	13.36	29.08	4.87	43.94	0.48	28.92	27.97	36.67	51.74	8.57	33.58	0.12	35.94	0.46	32.88	23.96	21.24
50.22	**12.89**	**38.19**	**6.09**	**41.03**	**1.39**	**36.17**	**38.98**	**47.88**	**52.75**	**12.82**	**39.84**	**7.77**	**42.35**	**1.15**	**37.66**	**41.25**	**47.97**
21.94	3.95	17.92	2.25	11.00	1.64	10.12	12.88	20.43	25.83	5.86	19.17	5.16	19.62	0.71	10.67	18.38	19.00
5.17	0.93	4.23	0.53	2.59	0.39	2.39	3.04	4.82	6.09	1.38	4.52	1.22	4.63	0.17	2.52	4.34	4.48

Key

b = Black Shoe | 7 = 7iron | f = Pressure Result | 1-9r = In-shoe Region (see figures 6.2 and 6.3)

g = Green Shoe | d = Driver | a = Average Result

y = Yellow Shoe

Green Shoe 7Iron Average **Raw Data 6.N** **Green Shoe Driver Average**

g7a1r	g7a2r	g7a3r	g7a4r	g7a5r	g7a6r	g7a7r	g7a8r	g7a9r	gda1r	gda2r	gda3r	gda4r	gda5r	gda6r	gda7r	gda8r	gda9r
49.72	12.42	46.34	11.9	57.84	2	39.06	50.08	33.36	36.18	12.04	39.96	9.36	59.46	1.36	55.18	72.87	68.36
45.28	14.72	32.86	7.22	55.98	0.44	32.04	49.34	76.6	38.64	10.4	36.4	10.52	59.52	1.14	34.84	56.82	77.8
68.02	13.9	51.5	10.14	71.36	0.12	27.56	52.28	52.84	34.97	15.6	49.96	11.3	65.9	0.22	31.04	59.72	67.92
19.7	27.66	23.75	10.22	35.58	0	23.08	15.52	18.16	41.68	16.38	10.62	8.36	20.76	0	22.18	17.4	20.3
58.94	11.68	59.06	10.22	70.38	1.44	62.08	78.22	70.54	74.14	20.76	72.1	12.34	83.56	1.18	57.48	70.68	63.56
52.84	22.12	62.95	9.38	78.92	1.22	48.78	43.96	33.72	97.02	16.36	61.02	14.84	40.56	1.24	28.18	38.76	43.84
67	14.86	60	10.36	70.46	0.8	31.88	59.22	73.86	37.56	13.42	37.22	9.82	55.76	0.58	40.76	64.26	66.22
68.38	21.64	74.46	15.46	70.66	.	38.94	21.16	16.34	34.22	12.04	43.24	13.64	54.66	0	43.64	44.94	28.24
55.28	12.42	48.32	9.34	70.18	1.62	40.16	73.28	79.38	57.58	14.87	50.66	8.44	68.54	1.8	38.64	69.66	80.86
52.84	12	36.46	8.24	41.48	2.36	42.34	76.72	83.82	47.1	10.94	40.58	10.82	47.5	2.5	48	54.98	78.96
39.3	9.12	21.24	6.93	23.14	.	27.28	24.8	29.34	24.42	19.76	15.08	2.08	17.28	.	33.32	32.42	40.34
60.2	16.98	42.02	15.1	46.14	2.26	40.9	59.02	61.1	56.4	14.7	40.1	11.1	43.5	1.6	36	52.8	55.6
13.42	15.16	11.52	13.32	23.26	.	25.9	26.68	31.54	42.97	19.04	11.32	11.46	25.08	.	34.1	24.26	33.04
22.36	30.52	19.74	15.68	25.66	.	27.86	27.46	31.89	31.98	29.87	16.9	11.9	29.4	.	25.2	19.2	23.97
51.86	25.97	16.16	18.82	33.24	.	28.78	29.86	24.9	14.82	19.76	12.68	13.92	37.28	.	25.64	26.68	21.22
22.82	28.52	16.58	12.7	26.08	.	23.78	19.02	23.24	14.68	19.86	12.42	9.74	19.78	.	25.34	28.6	33.34
60.44	14.06	38.9	12.16	34.18	1.74	17.58	33.78	91.96	38.97	17	42.18	13.58	44.72	2.54	21.74	41.52	42.97
38.94	24.16	25.9	5.94	34.52	.	35.6	26.06	29.65	30.46	15.97	20.82	1.04	32.34	.	32.9	35.06	31.1
47.07	**18.22**	**38.21**	**11.29**	**48.28**	**1.27**	**34.09**	**42.58**	**47.90**	**41.88**	**16.60**	**34.07**	**10.24**	**44.76**	**1.18**	**35.23**	**45.04**	**48.76**
17.42	6.73	18.60	3.43	19.81	0.83	10.66	20.55	25.51	19.92	4.60	18.48	3.66	18.76	0.87	10.54	18.31	21.20
4.11	1.59	4.39	0.81	4.67	0.20	2.52	4.85	6.02	4.70	1.09	4.36	0.86	4.43	0.20	2.49	4.32	5.00

Yellow Shoe 7Iron Average **Raw Data 6.O** **Yellow Shoe Driver Average**

y7a1r	y7a2r	y7a3r	y7a4r	y7a5r	y7a6r	y7a7r	y7a8r	y7a9r	yda1r	yda2r	yda3r	yda4r	yda5r	yda6r	yda7r	yda8r	yda9r
68.23	16.88	37.97	14.23	73.35	0.33	33.85	39.23	30.2	75.86	15.26	60.9	9.26	58.06	1.86	36.18	53.04	54.78
50.42	9.24	48.6	8.36	57.76	2.42	38.06	54.72	60.26	29.2	19.95	33.46	4.48	50.98	1.84	43.94	63.1	67.36
50.78	8.98	40.72	7.22	59.68	0.32	30.76	57.3	60.26	48.84	15.1	37.98	10.48	47.84	0.32	27.06	54.36	59.92
58.39	22.46	12.98	8.18	30.96	.	19.92	21.58	25.94	22.98	17.02	14.14	11.54	33.56	.	25.36	28.72	27.64
80.22	14.76	68.34	13.28	63.22	1.62	66.16	74.24	59.42	42.87	15.18	65.02	13.5	61.42	1.72	54.22	75.48	65.48
52.87	20.16	34.76	14.02	67.46	1.34	52.98	55.62	51.28	64.56	21.8	68.78	18.48	57.36	0.7	44.18	49.28	48.68
43.08	15.54	38.1	9.36	47.42	1.96	35.06	49.88	59.02	42.14	11.82	32.8	8.46	36.24	3.32	35.86	59.68	57.04
76.06	20.06	51.85	16.2	62.46	.	45.92	19.56	26.84	40.32	13.48	51.18	15.74	56.7	0.02	42.3	35.88	29.68
56.92	9.48	48.78	8.42	61.96	1.06	46.28	77.76	72.06	53.28	22.97	44.48	7.56	60.5	5	44.08	80.84	70.24
52.04	12.36	33.92	11.86	36.2	1.76	52.12	77.68	95.1	51.64	12.5	32.58	13.12	33.04	2.32	44.42	68.98	56.97
43.24	9.34	33.96	12.95	22.12	.	29.66	29.46	33.02	27.64	11.08	22.98	5.96	23.97	.	29.26	38.22	43.24
59.14	15.54	29.72	12.2	48.56	2.44	44.02	62.22	67.58	74.92	15.32	37.84	10.26	40.54	3.28	42.12	57.8	56.38
16.44	12.92	34.86	7.66	17.22	.	25.94	29.3	26.46	36.98	20.64	32.56	9.3	22.2	.	28.06	30.52	33.86
28.06	39.22	25.94	13.3	21.58	.	28.7	28.82	21.2	30.1	23.63	24.16	11.72	28.36	.	21.58	18.28	45.86
16.24	34.76	20.34	11.95	24.76	.	37.28	35.12	25.98	21	24.08	18.46	12.97	22.06	0	28	29.74	19.64
17.34	19.66	35.85	10.7	18.52	.	26.12	35.2	35.32	33.75	16.44	13.58	11.12	17.46	.	28.88	38.32	38.88
50.02	13.62	21.42	12.62	26.68	1.32	13.26	25.22	69.48	55.4	14.4	27.9	8	24.2	1	14.1	23.8	73.1
45.44	10.14	33.9	6.93	35.9	.	39.48	30.24	34.94	39.26	21.97	27.18	10.89	32.02	.	43.48	33.98	24.2
48.05	**16.95**	**36.22**	**11.08**	**43.10**	**1.46**	**36.98**	**44.62**	**47.46**	**43.93**	**17.37**	**35.89**	**10.71**	**39.25**	**1.78**	**35.17**	**46.67**	**48.50**
18.79	8.44	12.82	2.80	19.12	0.75	12.90	19.48	21.25	16.34	4.28	16.50	3.38	15.17	1.52	10.35	18.44	16.54
4.43	1.99	3.02	0.66	4.51	0.18	3.04	4.60	5.01	3.85	1.01	3.89	0.80	3.58	0.36	2.44	4.35	3.90

Black Shoe 7Iron Average **Raw Data 6.P** **Black Shoe Driver Average**

b7a1r	b7a2r	b7a3r	b7a4r	b7a5r	b7a6r	b7a7r	b7a8r	b7a9r	bda1r	bda2r	bda3r	bda4r	bda5r	bda6r	bda7r	bda8r	bda9r
23.53	26.66	3.54	39.54	5.84	45.7	22.74	21.64	21.64	11.85	18.94	5.84	24.38	8.96	47.3	41.43	35.66	30.18
22.84	25.72	11.46	40.46	6.62	50.9	20.74	23.3	48.5	22.38	28.36	10.1	38.6	6.46	44.5	20.48	16.62	40.28
22.06	43.04	4.53	24.52	3.72	30.2	11.86	16.28	35.58	25.76	42.04	3.53	27.14	0.16	44.97	22.54	23.6	37.96
17.4	21.88	10.96	32.06	1.02	38.56	25.32	32.34	41.34	16.56	22.18	12.04	34.82	0.66	47.4	26.88	27.36	39.78
19.02	38.54	3.53	30.7	1.2	35.22	18.1	26.26	46.16	21.38	44.72	1.32	33.42	1.34	37	27.52	35.62	53.08
24.64	54.5	12.28	43.28	7.35	24.76	21.06	16.22	24.66	23.86	57.6	12.38	55.66	0.44	32.5	17.96	17.64	32
22.6	35.52	4.44	41.28	6.96	58.24	28.8	25	65.72	18.32	28.06	5.1	40.56	5.75	59.94	31.18	27.18	58.3
21.06	21.48	13.35	41.24	3.96	72.3	35.06	31.06	66.18	25.94	31.36	10	47.16	10	62.76	32.2	27.58	64.3
35.5	48.66	11.42	38.9	2.62	30.42	26.38	19.54	37.73	29.18	40.42	11.53	35.06	2.76	29.78	28.42	19.8	22.16
28.24	40.44	3.66	23.76	4.63	45.48	33.58	40.56	38.54	30.28	45.84	4.56	27.06	6.14	47.86	32.5	38.46	36.26
34.56	40.18	4.14	33.08	1.74	36.24	23.58	32.84	42.7	36.96	49.88	4.56	34.94	1.98	33.54	21.58	32.28	50.28
15.1	18.14	11.16	32.52	3.64	44.76	32.48	35.13	49.54	14.96	20.02	13.15	29.54	0.92	57.6	40.24	39.3	59.06
37.7	45.54	4.88	35.64	1	25.23	29.42	24.36	38.32	37.66	50.96	4.96	40.58	0.94	24.58	31.9	25.94	41.46
12.53	15.72	8.96	24.76	3.64	33.24	29.02	31.42	44.52	12.96	15.22	4.64	27.4	4.57	47.02	31.22	29.88	51.4
17.16	43.04	10.9	57.14	3.74	68.01	17.5	29.72	65.48	17.16	35	9.95	49.46	0.13	61.87	34.4	34.78	51.43
12.52	23.84	11.42	40.04	2.64	71.43	28.24	38.58	68.14	26.95	47.41	13.76	59.3	0.18	55.68	42.88	51.1	58.82
11.72	54.96	2.64	52.06	1.28	55.94	34.24	29.82	45.56	12.26	34.46	4.87	41.56	1.12	61.64	46.64	42.62	58.4
14.72	22.74	3.46	19.26	6.75	24.92	31.53	34.42	22.1	15.06	28.14	4.9	19.4	6.42	23.44	71.44	28.2	37.87
21.83	**34.48**	**7.60**	**36.12**	**3.80**	**43.98**	**26.09**	**28.25**	**44.58**	**22.19**	**35.59**	**7.62**	**37.00**	**3.27**	**45.52**	**33.41**	**30.76**	**45.72**
7.95	12.63	3.95	9.77	2.17	15.85	6.50	7.14	14.54	8.01	12.41	3.90	10.82	3.24	12.96	12.38	8.95	11.96
1.88	2.98	0.93	2.30	0.51	3.74	1.53	1.68	3.43	1.89	2.93	0.92	2.55	0.77	3.06	2.92	2.11	2.82

Key

b = Black Shoe 7 = 7iron f = Pressure Result 1-9r = In-shoe Region (see figures 6.2 and 6.3)
g = Green Shoe d = Driver a = Average Result
y = Yellow Shoe

Green Shoe 7Iron Average **Raw Data 6.Q** **Green Shoe Driver Average**

g7a1r	g7a2r	g7a3r	g7a4r	g7a5r	g7a6r	g7a7r	g7a8r	g7a9r	gda1r	gda2r	gda3r	gda4r	gda5r	gda6r	gda7r	gda8r	gda9r
19.06	25.56	13.72	29.86	7.24	43.58	27.42	12.2	18.12	15.9	24.66	10.38	26.14	7.34	54.72	26.94	20.56	33.65
20.94	25.38	11.72	30.4	6.31	50.32	28.06	38.42	50.8	24.96	36.36	12.12	37.82	6.66	37.96	19.42	23.74	32.96
26.54	45.38	8.06	24.18	5.54	34.63	19.82	18.5	34.1	26.5	42.94	7.56	30.92	0.46	48.36	19.46	22.42	35.5
17.56	22.98	14.94	31.14	2.64	42.38	23.62	29.96	39.43	12.76	23.53	12.4	21.92	5.82	53.14	27.94	35.94	40.18
30.12	42.3	7.92	29.16	3.08	43.3	21.9	32	41.52	21.96	43.76	9.28	31.7	1.28	45.96	19.82	33.28	42.22
26.75	41.84	24.42	43.18	4.75	44.53	20.14	32.23	30.7	37.9	55.28	13.22	47.2	0.36	26.82	22.32	24.29	25.92
32.5	36.2	11.74	37.26	5.08	58.34	22.68	28.46	45.64	26.3	30.04	14.48	33.96	7.45	53.54	29.36	36.48	46.98
16.18	16.24	17.46	26.38	3.64	55.68	35.08	47.84	73.8	14.4	16.46	15.96	31.96	5.64	57.52	32.78	37.32	58.44
25.32	29.22	14.8	29.26	1.58	32.83	27.12	27.02	33.09	26.74	30.44	15.6	33.7	1.54	40.86	30.86	28.44	26.44
30.76	40.68	9.98	24.32	7.35	44.28	36.46	39.53	45.2	35.5	47.64	11.62	29	8.98	49.18	44.38	44.53	48.32
26.84	35.48	11.1	28.16	5.64	31.43	37.54	45.8	52.16	25.02	47.48	12.16	31.26	0.82	33.97	31.56	35.48	48.52
19.7	23.44	12.18	31.82	1.16	47.26	33.48	42.4	43.42	16.54	21.66	11.5	28.66	1.16	45.94	43.78	42.96	57.88
23.64	49.06	11.92	35.3	3.63	33.34	29.14	33.68	43.02	45.5	43.74	12.7	41.9	0	31	31.2	36.8	36.3
8.18	9.56	3.78	21.32	1.46	31.14	35.6	42.64	44.9	10.88	14.58	9.53	22.38	1.5	47.32	31.76	39.66	45.92
28.9	46.02	10.42	52.28	3.62	71.64	29.46	33	61.88	34.8	56.7	10.1	62.8	0.1	76.1	36.86	30.4	68.9
25.46	31.48	12.4	41.4	1.53	32.87	22.06	37.58	58.48	21.68	48.98	15.54	47.84	0.08	53.85	35.26	44.36	45.38
12.06	51.4	10.4	46.78	2.68	50.7	26.66	32.08	40.1	12.18	30.26	5.12	29.54	3.8	58.88	41.42	51.9	58.76
15.94	25.66	8.82	21.58	4.44	42.64	32.53	31.18	21.98	14.86	20.86	10.3	17.18	6.72	29.47	46.56	31.7	23.86
22.58	**33.22**	**11.99**	**32.43**	**3.97**	**43.94**	**28.27**	**33.58**	**43.24**	**23.58**	**35.30**	**11.64**	**33.66**	**3.32**	**46.92**	**31.76**	**34.46**	**43.12**
6.78	11.79	4.36	8.71	1.96	10.79	5.81	8.97	13.54	9.90	13.40	2.84	10.83	3.16	12.26	8.52	8.55	12.60
1.60	2.78	1.03	2.06	0.46	2.55	1.37	2.11	3.19	2.34	3.16	0.67	2.56	0.75	2.89	2.01	2.02	2.97

Yellow Shoe 7Iron Average **Raw Data 6.R** **Yellow Shoe Driver Average**

y7a1r	y7a2r	y7a3r	y7a4r	y7a5r	y7a6r	y7a7r	y7a8r	y7a9r	yda1r	yda2r	yda3r	yda4r	yda5r	yda6r	yda7r	yda8r	yda9r
12.03	24.55	12.63	30.65	5.64	40.48	35.62	49.5	28.35	18.8	25.8	11.5	23.96	9.54	46.34	26.2	30.78	22.62
26.42	33.14	11.7	38.84	4.82	58.3	24.48	36.12	42.76	24.04	31.12	11.34	35.78	10.38	50.24	25	28.2	35.4
20.02	32.8	7.43	24.34	5.62	31.82	26.22	36.23	48.96	21.44	33.44	5.96	22.18	.	34.68	21.16	26.22	39.42
14.06	15.1	12.14	43.83	1.96	28.94	29.54	42.32	31.28	9.98	16.06	11.84	28.96	1.48	39.52	28.56	38.78	41.62
24.68	39.18	7.5	28.68	2	35.5	25.32	37.38	47.62	35.46	52.48	10.34	40.1	1.7	38.34	27.38	38.08	45.52
37.7	53.1	12.43	39.18	4	30.32	16.96	38.42	28.06	39.86	52.8	11.8	39.28	0.1	28.18	16.44	18.1	26.08
23.64	33.46	11	33.84	2.46	52.72	35.24	40.12	58.1	22.36	26.18	7.36	29.62	2.04	47.3	29.8	34.28	43.48
11.58	12.4	11.18	41.53	4.64	46.84	46.88	47.9	46.75	15.14	18.38	9.76	29.26	2.74	47.22	26.36	30.28	50.78
27.14	40.46	15.4	31.38	2.7	15.36	32.84	42.41	30.3	25.84	33.6	14.92	28.08	4.14	21.85	35.5	27.94	24.64
31.42	36.24	10.82	24.28	4.75	53.3	33.25	39.16	51.3	34.68	41.06	12.5	28.86	9.54	51.5	39.74	47.68	44
27.16	36.54	12.24	26.22	2.54	31.42	30.9	48.06	50.02	30.66	44.76	11.28	25.64	0.04	17.68	22.4	33.08	38.78
14.16	21.54	8.68	26.74	3.64	33.76	33.5	40.92	46.34	13.96	21.58	10.24	31.18	0.74	39.46	45.08	58.92	65.12
31.62	45.16	7.58	31.54	2.64	21.48	30.4	36.38	34.5	34.56	52.88	7.98	32.42	3.64	23.74	33.52	39	40.66
11.26	18.12	9.32	21.86	2.54	31.53	27.38	39.4	41.14	11.56	19.44	8.84	27.2	0.36	29.48	31.16	46.08	53.9
1.42	72.5	4.25	25.63	.	55.66	18.04	31.52	57.82	12.93	47.95	5.28	33.96	8.54	56.26	38.92	37.44	54.32
26.14	48.02	9.74	52.9	1.53	51.53	28.2	40.46	68.64	39.2	72.18	13.42	64.92	0.84	55.28	39.4	43.08	65.24
10	38.38	3.52	38.46	2.59	46.42	31.63	48.25	53.28	18.42	29.9	7.76	34.66	1.04	56.7	40.44	49.96	56.6
19.04	24	13.24	27.06	1.93	24.08	47.76	39.24	24.96	19	22	14.5	43.95	0.5	23.86	76	31.8	33.2
20.53	**34.71**	**10.04**	**32.61**	**3.29**	**38.30**	**30.79**	**40.77**	**43.90**	**23.77**	**35.65**	**10.37**	**33.33**	**3.37**	**39.31**	**33.50**	**36.65**	**43.41**
9.44	14.72	3.11	8.28	1.35	12.79	7.94	4.93	12.21	9.80	15.44	2.75	9.74	3.70	12.80	13.11	9.87	12.63
2.23	3.47	0.73	1.95	0.32	3.02	1.87	1.16	2.88	2.31	3.64	0.65	2.30	0.87	3.02	3.09	2.33	2.98

APPENDIX H

(Relevant to Chapter 6)

Ground Action Force Raw Data

DRIVER	Black FF Tz max value (N.m)	Black FF Tz max time (s)	Black FF Tz Range (N.m)	Black BF Tz max value (N.m)	Black BF Tz max time (s)	Black BF Tz Range (N.m)
	12.20	2.76	43.87	6.27	2.55	11.85
	20.12	4.07	30.07	7.74	3.79	14.77
	13.70	2.73	44.84	6.30	3.69	16.25
	14.90	3.06	38.72	6.86	2.38	12.88
	17.30	3.10	33.78	9.36	3.25	10.87
	15.86	2.83	41.74	8.65	2.98	11.88
	23.94	4.57	33.38	4.90	4.69	10.36
	18.63	4.60	40.78	5.73	2.77	13.65
	18.98	2.49	41.73	9.59	3.82	16.26
	25.59	3.94	36.10	6.83	6.13	16.01
	17.27	2.73	40.15	8.74	4.29	10.49
	24.47	2.84	40.72	7.85	2.88	11.59
	18.78	3.60	41.73	9.57	3.69	11.66
	22.44	3.67	37.78	6.24	2.34	15.73
	25.97	2.18	38.90	7.93	2.66	12.68
	22.65	4.48	46.98	5.91	2.77	14.46
	21.36	2.98	38.95	7.68	4.65	11.90
	21.10	2.82	36.75	4.49	1.73	14.58
Mean	**19.74**	**3.30**	**39.28**	**7.26**	**3.39**	**13.21**
SD	4.06	0.75	4.23	1.56	1.07	2.04
SE	0.96	0.18	1.00	0.37	0.25	0.48

Ground Action Force Raw Data

DRIVER	Green FF Tz max value (N.m)	Green FF Tz max time (s)	Green FF Tz Range (N.m)	Green BF Tz max value (N.m)	Green BF Tz max time (s)	Green BF Tz Range (N.m)
	22.89	2.89	44.74	6.44	4.20	16.34
	20.46	4.92	41.77	8.35	2.77	11.87
	27.37	2.46	39.46	6.55	2.66	15.11
	16.90	3.94	31.37	9.24	2.09	15.32
	17.21	3.04	44.68	7.56	3.19	11.68
	17.37	2.08	30.56	10.64	2.96	15.45
	16.55	3.00	25.32	8.46	4.60	11.76
	14.58	3.24	44.87	8.47	3.64	15.68
	21.54	2.26	42.72	10.56	2.68	13.48
	23.62	3.98	36.83	9.44	3.98	12.99
	26.57	4.20	41.75	8.35	3.86	18.41
	17.42	4.01	36.94	5.75	2.81	16.95
	20.25	2.72	31.77	7.46	3.87	14.99
	22.87	2.17	46.74	8.96	2.69	15.01
	25.26	3.60	33.05	5.87	2.77	14.54
	23.85	3.79	35.08	4.42	3.90	14.33
	19.26	2.78	40.75	7.55	2.79	16.77
	20.72	3.43	38.36	7.04	2.24	16.11
Mean	**20.82**	**3.25**	**38.15**	**7.84**	**3.20**	**14.82**
SD	3.71	0.79	5.98	1.66	0.72	1.88
SE	0.87	0.19	1.41	0.39	0.17	0.44

Ground Action Force Raw Data

DRIVER	Yellow FF Tz max value (N.m)	Yellow FF Tz max time (s)	Yellow FF Tz Range (N.m)	Yellow BF Tz max value (N.m)	Yellow BF Tz max time (s)	Yellow BF Tz Range (N.m)
	22.44	1.78	34.96	6.33	4.22	12.88
	16.56	2.40	41.61	10.44	3.86	16.72
	14.36	2.75	40.64	5.17	2.90	13.87
	20.72	2.83	26.69	6.85	2.89	14.88
	17.75	2.00	25.48	7.54	4.17	14.55
	21.88	3.18	35.61	9.33	4.66	12.98
	20.25	2.76	41.75	8.44	2.88	10.87
	16.98	3.19	41.73	5.18	3.82	15.92
	20.38	3.34	42.62	9.70	3.77	14.88
	33.67	2.58	43.51	7.40	2.77	16.11
	18.48	4.19	41.54	5.74	3.87	11.97
	21.37	2.84	39.77	5.82	2.87	13.68
	19.37	3.73	36.74	7.96	3.03	16.44
	15.55	3.53	41.63	8.45	2.98	16.89
	21.55	3.81	40.44	7.76	2.48	11.03
	26.32	2.83	37.39	6.61	2.90	16.99
	21.86	2.63	41.56	4.92	5.30	13.98
	19.38	2.83	47.22	7.33	2.56	14.33
Mean	**20.49**	**2.96**	**38.94**	**7.28**	**3.44**	**14.39**
SD	4.35	0.62	5.52	1.61	0.79	1.93
SE	1.02	0.15	1.30	0.38	0.19	0.45

Ground Action Force Raw Data

7IRON	Black FF Tz max value (N.m)	Black FF Tz max time (s)	Black FF Tz Range (N.m)	Black BF Tz max value (N.m)	Black BF Tz max time (s)	Black BF Tz Range (N.m)
	20.33	3.23	39.74	3.77	4.86	11.64
	19.01	2.20	25.96	5.77	3.42	10.51
	17.40	3.52	33.73	2.25	4.88	12.63
	16.22	2.87	33.13	7.96	5.54	10.75
	17.44	3.22	40.84	3.93	2.37	13.74
	19.65	2.83	41.85	8.95	4.95	11.72
	20.21	2.72	37.06	3.54	5.52	14.73
	22.63	2.85	36.89	5.54	2.94	13.62
	17.66	2.34	35.85	5.88	3.81	11.62
	20.65	2.48	41.27	8.66	4.86	14.73
	19.55	3.70	40.56	6.88	5.67	11.52
	18.65	4.10	27.67	5.43	4.21	15.82
	24.56	3.68	33.61	7.76	4.00	10.52
	19.72	3.46	35.79	6.05	4.79	11.56
	20.76	2.73	41.74	5.80	4.76	10.52
	23.41	3.03	33.44	6.91	5.07	11.62
	19.97	2.94	37.85	5.18	4.76	15.95
	21.77	4.15	37.65	8.91	3.08	13.62
Mean	**19.98**	**3.11**	**36.37**	**6.06**	**4.42**	**12.60**
SD	2.17	0.56	4.57	1.93	0.95	1.82
SE	0.51	0.13	1.08	0.45	0.22	0.43

Ground Action Force Raw Data

7IRON	Green FF Tz max value (N.m)	Green FF Tz max time (s)	Green FF Tz Range (N.m)	Green BF Tz max value (N.m)	Green BF Tz max time (s)	Green BF Tz Range (N.m)
	20.65	3.48	38.47	7.56	5.62	16.13
	17.25	1.93	40.87	6.84	3.52	11.55
	28.41	2.98	44.11	4.92	3.75	13.62
	20.56	3.63	39.44	6.88	4.21	11.67
	18.88	3.20	28.18	5.48	3.45	13.72
	16.53	3.54	27.21	5.07	4.11	12.63
	24.88	3.54	35.78	6.88	2.87	11.65
	25.88	2.60	31.98	4.71	3.21	13.78
	22.77	2.77	42.90	7.76	3.19	11.75
	22.79	4.05	36.88	6.87	5.92	14.72
	27.86	3.53	37.76	5.99	5.63	12.76
	21.66	2.95	33.32	4.07	5.44	13.74
	18.75	2.97	38.87	6.44	3.80	11.73
	21.96	3.18	35.15	7.77	6.51	13.63
	19.66	3.54	39.77	5.76	7.13	14.83
	23.58	3.22	34.33	8.91	6.56	12.55
	19.83	2.99	36.87	6.05	5.19	11.61
	17.50	3.28	41.08	5.03	4.27	12.85
Mean	**21.63**	**3.19**	**36.83**	**6.28**	**4.69**	**13.05**
SD	3.49	0.47	4.61	1.27	1.33	1.32
SE	0.82	0.11	1.09	0.30	0.31	0.31

Ground Action Force Raw Data

7IRON	Yellow FF Tz max value (N.m)	Yellow FF Tz max time (s)	Yellow FF Tz Range (N.m)	Yellow BF Tz max value (N.m)	Yellow BF Tz max time (s)	Yellow BF Tz Range (N.m)
	22.85	2.63	35.96	6.10	6.55	11.75
	17.98	3.97	40.44	7.66	5.34	12.77
	28.70	3.17	35.19	3.37	6.13	10.75
	21.79	1.81	38.99	7.88	3.97	13.74
	23.87	3.08	27.85	7.07	3.20	12.75
	21.97	2.86	32.56	8.69	4.38	14.85
	26.55	2.49	31.86	7.09	3.11	14.63
	19.28	3.33	40.35	8.88	3.14	12.73
	21.54	3.44	33.23	6.88	5.38	11.26
	19.08	4.10	37.91	7.88	5.19	13.63
	24.10	3.54	40.44	6.77	5.02	14.65
	20.79	3.82	39.05	6.02	4.08	13.76
	23.86	2.65	36.96	5.97	6.46	12.34
	21.95	3.38	39.44	6.68	4.89	14.63
	17.87	3.79	29.76	4.62	3.44	10.65
	19.79	4.15	40.27	7.54	5.52	12.54
	13.21	2.44	38.75	5.67	6.44	14.61
	16.28	3.15	40.54	8.57	6.21	12.55
Mean	**21.19**	**3.21**	**36.64**	**6.85**	**4.91**	**13.03**
SD	3.69	0.64	4.02	1.42	1.21	1.37
SE	0.87	0.15	0.95	0.33	0.28	0.32

APPENDIX I

(Published Work Arising from this Thesis)

FOOT MOVEMENT PATTERNS DURING THE GOLF SWING

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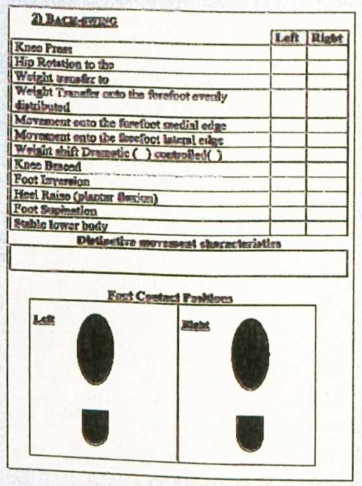
Reaching a better understanding of golf through science

The swing is fundamental to golf performance. The golf swing involves a rotary power build up and therefore, the action of the golfer during the swing must start at the feet – the only fixed point. Slavin and Williams (1995) identified the importance of foot function, with the biomechanics of the foot playing a critical, active and necessary role in the transference of weight and an efficient swing. The purpose of the present study was to identify foot and lower leg movements during the golf swing using notational analysis methods.

Method

Fifty-three golfers volunteered for the study. Subjects were observed during a tee shot (523 yards / 466 meters). Handicap group, club selection, ball position at address, shoe manufacturer and type of traction and cleat (i.e. spikes or alternatives) were noted. The turf condition allowed penetration of the subject's spikes. Shot outcome was observed as straight, hook or slice. Notation began when the player placed the ball on a tee and set-up into the address position. A tripod mounted JVC GR-DVL 150 digital video camera was used to film the frontal plane of the shot. Hip, knee and foot movements were assessed to identify individual body movements throughout the golfing performance. Each lower body movement was stored on video and recorded on assessment sheets for subsequent analysis (see figure 1). Any slipping or irregular foot movements during the swing were recorded. The non-parametric data was analysed using descriptive statistics.


2) BACK-SWING

	Left	Right
Knee Press		
Hip Rotation to the		
Weight transfer to		
Weight Transfer onto the forefoot evenly distributed		
Movement onto the forefoot medial edge		
Movement onto the forefoot lateral edge		
Weight shift Dramatic ( ) controlled ( )		
Knee Braced		
Foot Inversion		
Heel Raise (planter flexion)		
Foot Supination		
Stable lower body		

Distinctive movement characteristics

Foot Contact Positions

Left Right

Figure 1: Assessment Sheet

Results

All notation and results were described for a right handed golfer. The results of the study indicated that of the fifty-three players analysed 20.8% had low (0-7), 41.5% had mid (8-14) and 37.7% had high (15+) handicaps. Of the fifty-three participants 60.4% hit straight shots, 7.5% hooked, 18.9% sliced and 13.2 % miss hit their shots (see figure 2).

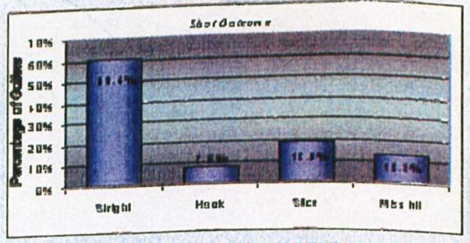


Figure 2: Shot Outcomes.

All subjects selected 4 iron or above with the majority (37.7%) selecting a driver. At address 60.4% located the ball off the front (left) foot, 35.8% off the middle and 3.8% off the rear (right) foot (Figure 3), with 5.7% adopting a closed stance, 86.8% with a mid and 7.5% with a wide stance.

Of the fifty-three participants 47.2% used spiked and 52.8% used alternative spiked shoes, with 60.4% maintaining a stable footing throughout their shot, while 39.6% identified slipping during the swing (Figure 4).

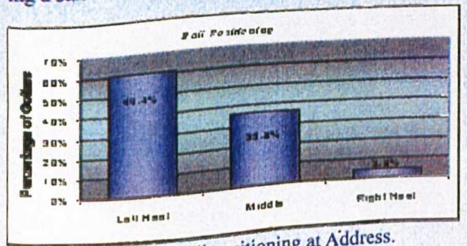


Figure 3: Ball positioning at Address.

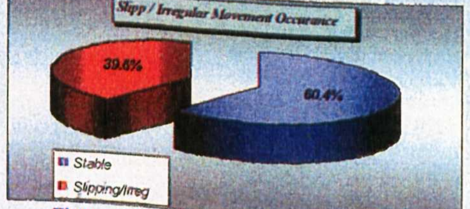


Figure 4: Slipping or Irregular Foot Movement Patterns Occurring During the Swing.

Analysis revealed that 1.9% slipped on their right foot during the downswing, 3.8% slipped on their left foot during the back-swing, 15.1% slipped on their left-foot during the downswing and 18.9% slipped on their left-foot during the follow through (Figure 5).

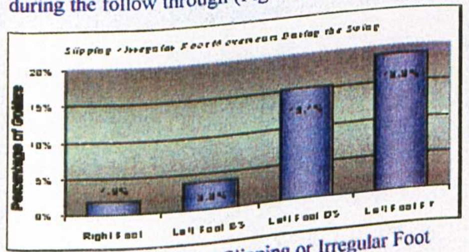


Figure 5: Where the Slipping or Irregular Foot Movements Occurred During the Swing

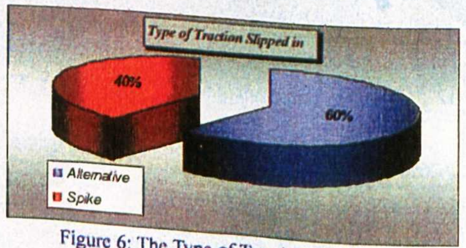


Figure 6: The Type of Traction the Slips or Irregular Foot Movements Occurred in.

The results highlight greater amounts of slipping in the left foot compared to the right. Sixty percent of the slips occurred wearing alternative spikes with 40% occurring in spiked shoes (Figure 5).

The swing was broken down into four phases for notation. The initial address position located the club and body over the ball with the left shoulder toward the target

The first initial action identified a "pressing" or "cocking" motion in 47.2% of the golfers in which the golfer slowly adducted the right knee in towards the left one and then, as the knee returns to its original position, the withdrawal of the hands and club then followed (Picture 1).

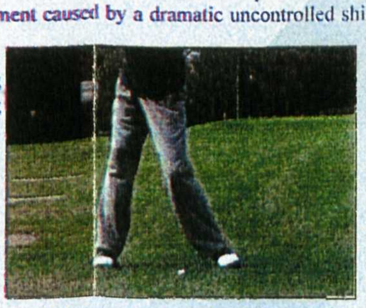

Picture 1: Knee "Press" Movement.

Similar findings were found within the results of Carlsoo (1967) who suggested that this might serve to help the golfer initiate the back-swing in a systemic and relaxed manor, but apart from this it would appear to have no particular merit in the swing performance.

The aim of the back-swing is to put the golfer and the club into the optimum position from which to start the downswing. A simultaneous backward movement of the club-head and a rotation of the trunk to the right then occurred, causing a dramatic weight shift, moving onto the right foot with the left foot carrying less weight. The weight either appeared evenly distributed on the back foot (34%), on the lateral side (30.2%) or appeared to maintained a slight medial position (35.8%) recognised by the rear foot position.

This weight shift must occur in a controlled manner to maintain a stable platform. Many of the unsuccessful shots derived from a large "swaying" movement caused by a dramatic uncontrolled shifting of body weight to the lateral edge of the right foot (24.5%).

One of the critical elements during the swing was the constraint of the right knee during the back-swing (Picture 2).


Picture 2: Braced Right Leg During the back-swing.

This was identified within the lower handicapped players who kept their right knee braced close to its address location during the back-swing, putting the knees in position to lead the downswing. The knee constraint enabled the development of torque through rotation to the right around the axis of the centre of the leg creating a "wind up motion". The right leg movement depended on the stability and inherent tension created by the shoe to ground interaction and possibly the right ankle joint.

As the right foot remained in a solid position on the back-swing without excess rolling to the lateral edge (Picture 3), the left foot was in turn rolling to the medial edge and into an everted position (84.9%) (Picture 4).


Picture 3: Right Foot Lateral Support.


Picture 4: Left Foot Roll to the Medial Edge.

Left heel raise occurred in 26.4% of the golfers as a result of foot planter flexion helping promote a full shoulder turn, until the golf club was situated over the right shoulder. Completion of the back-swing placed the weight on the right foot, evenly distributing the body weight between forefoot and rear foot and the mid to lateral border, with the weight left on the front foot rolling to the medial side.

The downward movement involved a rapid shift of weight from right foot to the left foot with the forward motion of the golf club. Rotation started in the opposite direction to the back-swing.

The objective of the downswing is to have the club-head arrive at the point of impact moving at maximum speed in the required direction and with the face of the club pointing in the same direction (Pforringer, and Rosemeyer, 1989).

At impact the club travelled across the mid line between the feet towards the left hip, causing it to pivot in an inclined plane rapidly to make way for the hands and club inducing the body to rotate to face the target. The momentum of the club continued carrying the head on towards the target until the extended arms forced the club around and over the shoulders. This movement caused the right leg to swivel and the knee joint to flex adducting until it came into close proximity to the left leg. Ninety four percent of the golfers had their knees bent at impact.

The follow-though naturally caused a rolling of the right foot to the medial edge planter flexing raising the heel and onto the toe (Picture 6).


Picture 6: Right Foot Rolling onto the Toe During the Follow Through.


Picture 7: Left Foot "Buckling" During the Follow Through.

The left foot moved often dramatically onto the lateral edge, in the worst case it caused a "buckling" of the ankle (28.3%) in order to stop the forward momentum (Picture 7).

Discussion

* Poorer golfers appeared to generate faster swings through quicker body movements than the lower handicapped players but were unable to control these movements generated due to poor timing and control. Their swing had a typical casting motion from the top of the back-swing down into the follow through, generating maximum forces at the time when the body is least able to control them. The natural follow through of the club often did not materialise as the golfer had to apply large decelerations to the club to avoid injury. This open faced swing often induced sliced shots (Figures 4,5 and 6).

* The right and left foot functioned completely different from one another and showed no symmetry. The demands placed on the right foot / shoe during the swing was relatively minor performing a rocking movement, which at the end of the swing rolled onto the antero-medial edge of the big toe and finally on the tip of the shoe.

* The left foot behaved quite differently. There was a shift of the weight from the medial to the lateral edge of the foot and a supination of the left foot in both the ankle and subtalar joints. In extreme cases this movement terminated in a "buckling" of the foot of almost 90 degrees and come to rest on the lateral edged of the foot, on the lateral edge of the shoe (Picture 7).

Conclusion

* The results support the findings of Slavin and Williams (1995) in identifying the importance of the foot and lower leg actions in the generation of force, control and offering support throughout the swing.

* During the back-swing the left foot everted while during the downswing the left foot inverted but the right foot everted. It appeared that foot eversion maintained foot stability during the swing.

* The findings identify concern with regard to the amount of current support and traction offered by golf shoes during the swing process. The left foot was subjected to stress during the shot as the right foot maintained stability during the swing. Preliminary information indicates that the golf shoe does not appear to offer sufficient lateral support for the left foot or specifically address the movement processes involved during the weight transfer during the swing phase.

* The methodology employed provided a structured recording of the lower body golfing movements enabling detailed analysis to be performed.

References

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